

LEARNING PHONOTACTIC CONSTRAINTS IN THE PRODUCTION OF NON-NATIVE
CONSONANT CLUSTERS, AS REFLECTED IN SPEECH ERRORS

BY

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THESIS

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ABSTRACT

Experiments in which participants produce sounds under artificial phonotactic constraints show that speakers are able to acquire new speech patterns following minimal exposure, even when these patterns involve sequences unattested in the participants' native languages (e.g., Dell, Reed, Adams, & Meyer, 2000; Taylor and Houghton, 2005; Whalen & Dell, 2006).

However, if the phonotactic learning mechanism is robust to such a degree, why do stable linguistic patterns exist—across languages, across time, even across an individual's language patterns over his lifetime? The literature suggests that phonotactic learning is moderated by universal markedness constraints (e.g., Berent, Steriade, Lennertz, & Vaknin, 2007; Redford, 2008).

To that end, this study aims to provide evidence for the idea of an adaptive language production mechanism that is sensitive to recent experience, but subject to a markedness effect, with experiments showing that the relative ease with which speakers learn various phonotactic constraints corresponds to universal markedness preferences. Phonotactic constraint adherence in speech can be assessed by examining movement errors, or errors in which sounds slip within an utterance.

An error in which the sound lands in the “legal” syllable edge, or the sound's position in the intended syllable, demonstrates adherence to the particular constraint involving the moved segment. In the present study, native English speakers recited syllables including unattested marked and unmarked consonant clusters under artificial phonotactics constraints, following training in articulating the unattested segments. If speakers are sensitive to markedness in

unfamiliar consonant clusters and capable of learning recently encountered patterns, movement errors involving the unmarked unattested cluster in the production task should be more likely to obey novel positional constraints than movement errors involving the marked unattested cluster. The results showed that participants were more likely to adhere to novel phonotactic constraints involving the unmarked unattested cluster, confirming that markedness constraints on unfamiliar consonant clusters influenced the acquisition of phonotactic constraints.

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CHAPTER 1: INTRODUCTION

The present study aims to determine whether native speakers of English are capable of learning non-native phonotactic constraints following recently produced patterns, with adherence to these constraints degrading according to markedness preferences.

Whether a speaker has learned non-native phonotactics is determined by examining rates of phonotactic constraint adherence during a production task. Phonotactic constraint adherence in speech can be deduced from the nature of elicited movement errors, or errors in which sounds slip within an utterance, and to what degree they adhere to patterns established in the stimuli. Speakers who have been exposed to segments occurring in syllable positions in which they would not occur in natural speech—or would not occur in the native language at all—are more likely to make errors in which sounds move into the same syllable edge as presented in the target, or intended, syllable. This type of slip is “legal” as the syllable edge is preserved; an “illegal” movement error, on the other hand, occurs when the moved segment disobeys the established constraints, moving into the other syllable edge.

Studies in which participants recite lists of syllables under artificial phonotactic constraints have shown that patterns can be abstracted, or learned, very quickly, even over a single session—demonstrating that language production mechanisms are highly adaptive and sensitive to recent experience. Similar findings involving sequences with non-native sounds offer more definitive support for claims that recent language exposure may result in fundamental changes to the phonological processing system, rather than demonstrating only a local bias

primed by prior exposure (e.g., Dell, Reed, Adams, and Meyer, 2000; Taylor and Houghton, 2005; Whalen and Dell, 2006; Albright, 2007; Berent, Steriade, Lennertz, and Vaknin, 2007).

If an individual's speech patterns continually evolve, emerging with ongoing exposure to language, how do we account for diachronically stable, cross-linguistic patterns? The literature suggests that the language learning robustness is moderated at least in part by universal markedness constraints (e.g., Newport and Aslin, 2000; Redford, 2008).

The present study follows previous research in modeling markedness constraints as preferences concerning the sonority profiles of segments in certain syllable positions. To avoid the confound of prior exposure, the strategy used to isolate the markedness effect on learning involved a comparison of structures unattested in English (e.g., Redford, 2008, Berent et al., 2007). Thus, the hypothesis is formulated as follows: if speakers are sensitive to markedness in unattested consonant clusters and learning is constrained by universal markedness preferences, the unmarked unattested clusters in a speech production task should obey positional constraints at a higher rate than the marked unattested clusters.

Two experiments were carried out. In both, adult native speakers of American English were trained in articulating two consonant clusters, /tl/ and /gv/, as syllable onsets. Both clusters are unattested in English, but only /gv/ is marked by sonority for syllable onset position in English. The cluster /tl/, however, is unmarked by sonority in syllable onsets, due to its rising sonority profile.

Training was followed by a production task in which participants read sequences of syllables, in time to a metronome. In Experiment 1, each of these CCVCC syllables contained an "e" surrounded by two of eight unique consonant clusters, including those studied in the

training phase: /gv/, /tl/, /dr/, /sk/, /vd/, /lg/, /rk/, and /st/. Each sequence contained all possible permutations of four CCVCC syllables under certain positional constraints. The clusters /gv/, /tl/, /dr/, and /sk/ appeared in syllable onsets exclusively and /vd/, /lg/, /rk/, and /st/ appeared in syllable codas only.

Experiment 2 was identical to Experiment 1, with the exception of one aspect of the stimuli: while /gv/, /tl/, /dr/, /vd/, /lg/, and /rk/ were under the same positional constraints as in Experiment 1, /sk/ and /st/ appeared in onsets 50% of the time and in codas 50%. An illegal movement error rate involving /sk/ in Experiment 2 similar to that of /sk/ in Experiment 1 would imply that rates of constraint adherence for clusters in the stimuli did not reflect the learning of positional constraints.

The primary research in the current study is concerned with the acquisition of non-native phonotactic patterns and the proposal that, if markedness does constrain phonotactic learning, the constraint adherence rate for an unfamiliar cluster would reflect whether the cluster is marked in a given syllable position. That is, in both experiments, if the markedness of an unfamiliar cluster has no bearing on the ability to learn positional constraints, the illegal movement error rates for accidental productions involving these clusters would not be significantly different: the rate at which /tl/ moved to onset position during a slip would be similar to that at which /gv/ moved to onset position during a slip.

CHAPTER 2: LITERATURE REVIEW AND BACKGROUND

2.1 Sensitivity to phonotactic constraints and speech errors

Studies have shown that the phonological processing system is highly adept at abstraction and capable of continual, fundamental change over an individual's lifetime. The ability to rapidly acquire language patterns is universal and available from infancy—experiments have shown that infants are able to segment fluent speech into words by computing statistical relationships among neighboring sounds from only minutes of exposure (e.g., Mattys and Jusczyk, 2001; Saffran, Aslin, and Newport, 1996) and are also capable of abstracting newly learned phonotactic regularities to unstudied, or novel, syllables, demonstrating that linguistic experience is not necessarily obligatory in the rapid acquisition of phonotactic constraints (Chambers, Onishi, and Fisher, 2003).

Powerful sensitivity to language patterns continues through an individual's lifetime. Recent studies have demonstrated that adults are capable of acquiring artificial phonotactic constraints in syllable processing tasks involving perception and production (e.g., Dell, Reed, Adams, and Meyer, 2000; Warker and Dell, 2006; Taylor and Houghton, 2005; Onishi, Chambers, and Fisher, 2002).

In the studies cited here, phonotactic learning in production is revealed in tasks in which participants read syllables that include segments that are artificially constrained to certain positions in the syllable throughout the experiment such that a clear phonotactic pattern is established (e.g., Dell, Reed, Adams, and Meyer, 2000; Warker and Dell, 2006; Taylor and Houghton, 2005). Participants demonstrate acquisition of the experimental constraints with

speech errors in which segments tend to move into the positions in which they appear in the newly introduced patterns.

Speech movement errors are slips in which one segment in a sequence is replaced by another from a particular sequence (following e.g., Dell et al. 2000; Whalen and Dell, 2006). For example, when a speaker intends to say “king mill,” but produces “king kill,” the consonant /k/ erroneously moves to the onset of what was intended to be produced as “mill,” resulting in “kill.” This error accords with English phonotactics as /k/ may occur in the environment in the produced word.

A speaker is not likely to make an error in which the sound involved in the slip moves to a syllable edge in the produced utterance such that the result violates English phonotactics. For example, if the speaker intends “king mill” but the final sound in the first word moves to what was intended to be produced as “mill,” the resulting erroneous production is far more likely to be /mɪŋ/—with the velar nasal, /ŋ/, occupying the same position it did in “king”—rather than, for example, /ŋɪl/, in which /ŋ/ moves to syllable onset position. In the former case the error is termed *legal*, as it accords with English phonotactics; in the latter case the error is *illegal*, as it is a violation of the English phonotactic rule prohibiting /ŋ/ onsets.

The phenomenon described above—that speakers rarely produce syllables that violate the phonotactic constraints of the native language—is called the phonotactic regularity effect (Stemberger, 1983). The phonotactic regularity effect reflects the influence of language-wide constraints; local constraint adherence, on the other hand, reflects the syllable position effect, which refers to the notion that people make more legal movement errors than illegal, demonstrating a cross-language tendency for consonants to retain their syllable positions when

moving (Fromkin, 1971). In other words, the phonotactic regularity effect can be considered a (more general) formulation of the principle that misplaced speech sounds tend to reflect the positions in which they correctly occur.

It has been found that sounds under language-wide constraints are less likely to be involved in illegal movement errors than sounds that are under local constraints only—showing that the phonotactic regularity effect is stronger than the syllable position effect. That is, the phonotactic regularity effect can be considered a (more general) formulation of the principle that misplaced speech sounds tend to reflect the positions in which they correctly occur, implicating a language processing system that is sensitive to patterns at a various levels of generality: “the syllable position and phonotactic regularity effects can thus be thought of as two ends of a continuum of breadth-of-constraint with the former at the narrow end and the latter at the wide end.” (Dell, Reed, Adams, and Meyer, 2000)

Dell et al. (2000) conducted a number of experiments to clarify the degree and nature of sensitivity to constraints along this continuum with experiments manipulating various levels of constraints: local, experiment-wide, and language-wide.

In one experiment, native speakers of English read aloud strings of four CVC syllables. Each sequence was composed of eight consonants—/h/, /ŋ/, /m/, /n/, /k/, /g/, /f/, and /s/—and the vowel /e/, as in, for example, “fes gek meŋ hen.” Language-wide English constraints were modeled with /h/ and /ŋ/, as the former may occur in the onset only and the latter in the coda only. Local constraints were modeled by restricting the consonants /n/, /m/, /k/, and /g/ to appear only once in a sequence, either in the onset or coda of a syllable—but from sequence to sequence, these four consonants could appear in either coda or onset. Experiment-wide

constraints were modeled by restricting /f/ one syllable edge and /s/ to the other throughout the experiment (in order to provide evidence that the results of the experiment were not due to properties unique to /f/ and /s/, an additional experiment was carried out which was identical to the first, but with /k/ and /g/, rather than /f/ and /s/, restricted to onset and coda positions, respectively).

The expectation was that the elicited movement errors would illustrate varying sensitivity to patterns at different levels of generality, showing that since the experiment-wide constraints were imposed over the set of sequences presented to the subject during the experiment, and so were hypothetically situated in the middle of the breadth-of-constraint continuum, their influence should differ from the effects of the constraints at other points along the continuum. Specifically, the experimental constraints should show a lower adherence rate with a higher rate of illegal movement errors on the part of /f/ and /s/ as compared to the rate of illegal movement errors on the part of /h/ and /ŋ/, which are under language-wide constraints. A higher level of adherence to the experiment-wide constraints versus local positional constraints—or, equivalently, a lower rate of illegal movement errors involving the consonants /f/ and /s/ as compared to the rate of illegal movement errors involving the consonants /n/, /m/, /k/, and /g/—would indicate that experiment-wide constraint adherence is not simply a case of the syllable position effect.

The results showed that constraints at different levels of generality were obeyed at different rates: language-wide constraints were never disobeyed; local positional constraints were obeyed at the lowest rate, 68-78 % of the time; and adherence to newly introduced constraints constituted the middle ground, with the experiment-wide constraints obeyed 90-98% of the time.

Although the fact that the consonants that were only under experiment-wide constraints exhibited more illegal movement errors than did consonants under the language-wide constraints accords with the notion of a breadth-of-constraint continuum in which the language-wide constraints are situated at the most general end and experimental constraints are closer to the more specific, narrower end, it can be argued that rapid learning of experiment-wide constraints demonstrates only a sort of local tuning of language-wide constraints, rather than change at a fundamental level of the phonological processing system. This was a key issue for Taylor and Houghton (2005), motivating a series of experiments to find support for the idea of a breadth-of-constraint continuum proposed by Dell et al. (2000) by situating experiment-wide constraints along the continuum. That is, the authors question whether adherence to experiment-wide constraints shows lasting learning or merely reflects immediate bias of language-wide constraints. A replication of Dell et al.'s experiments showed that adherence to local positional constraints was not above chance and that the experiment-wide constraints align more strongly with the language-wide constraints. Additional experiments designed to investigate the robustness and time course of experiment constraints by reversing them during the experiment session showed that the effect of experiment-wide constraints is not long-lasting and weakens rapidly.

Taylor and Houghton (2005) concluded that adherence to experiment-wide constraints is a result of local tuning of an already-learned syllabic structure; however, learning of unfamiliar artificial constraints—that is, constraints absent from a speaker's linguistic experience—would provide stronger support for claims of fundamental changes to the phonological processing system. Whalen and Dell (2006) set out to provide such support with two experiments

illustrating the relative ease with which phonotactic knowledge involving constraints never before encountered in the native language—and its impact on speech errors—can be changed. In their study, native speakers of English were first trained to produce [ŋ] in the onset of a syllable, then recited sequences of syllables in two tasks: in one experimental condition [ŋ] occurred in the syllable onset only; in the second condition, [ŋ] appeared in both onset and coda positions. It was found that speakers produced errors in which [ŋ] tended to slip to the onset position, even when presented in the coda in the stimuli. Whalen and Dell's (2006) results demonstrated that recent experience “can actually change the core of the phonological processing system” even when simulated with constraints never before encountered in the native language outside the experiment context.

2.2 Markedness and phonotactic learning

The literature cited above describes the ability to quickly learn patterns in recently produced stimuli, even when these patterns involve sounds not present in the speaker's native language, thereby implicating phonotactic learning as a powerful and continually adaptive process. However, if language learning is so proficient at rapid pattern acquisition, why do stable linguistic structures exist across time, across languages, even across an individual's speech patterns throughout his lifetime? The literature suggests that the power of language learning is subject to a markedness effect, or moderated by constraints that reflect universal preferences for unmarked structures (e.g., Newport and Aslin, 2000; Redford, 2008).

Speech perception and production across all languages is governed by necessarily basic conditions—all speakers postulate a set of “independently similar constraints [that acts as] a source of systematic similarities among grammars and generates a structured phonological

typology” —implicating universally shared constraints on language learning (Hayes and Steriade, 2004). That is, structures that are typologically, or distributionally, marked—i.e. universally dispreferred—are also grammatically marked.

Hume (2008) defines markedness as a universal law “proposed to underlie language acquisition, relations among linguistic elements in synchronic systems, language change and language loss.” The enduring patterns in the grammars of all languages are unmarked—that is, they do not violate certain universal grammatical constraints—while marked patterns, though they may be considered well-formed at some point in the history of a language, are ultimately isolated and unstable, emerging only as transitional structures (Redford 2008).

Recent studies have explored this notion, expanding on the literature concerning the ability to learn unfamiliar patterns in recently produced stimuli with findings showing that speakers prefer well-formed structures even when these structures are absent from the native language experience and so unavailable for abstraction (e.g., Davidson 2006; Berent, Steriade, Lennertz, and Vaknin, 2007; Redford, 2008; Albright, 2007).

Two studies (Berent et al., 2007 and Redford, 2008) detailed below), investigated whether language learning is subject to a markedness effect not by focusing on distributional patterns of onset segments (e.g., /ŋ/ never appears in syllable onsets in English), but considering the role of a structure’s identity. As the particulars of a structure’s sonority profile classify it as (some degree of) marked or unmarked for the onset position within a syllable, the experiments focus on novel onset clusters composed of two consonants. Though these studies differ in the specifics of the hypotheses and implementation, the common supposition is that unmarked patterns should be easier to learn than marked patterns. As an introduction to more

comprehensive descriptions of these studies, the following is a brief overview of the principles underlying sonority markedness constraints.

Phonotactic constraints on syllables and their constituents can be expressed in terms of sonority. The universal Sonority Sequencing Principle (SSP) states that the sonority profile of a syllable must rise from the onset, peak, and then fall. In an onset consonant cluster, for example, the second consonant must be more sonorous than the first. The sonority of a sound is determined by the Sonority Hierarchy, in which the most sonorous segments are vowels, followed by the liquids, nasals, and obstruents, in that order. Table 1 illustrates the rankings of sound classes under the Sonority Hierarchy (e.g., Cairns and Feinstein, 1982, Roca and Johnson, 1999).

Sound class	Sonority ranking	
vowels	4	Most sonorous
liquids	3	
nasals	2	
obstruents	1	Least sonorous

Table 1. Sonority Hierarchy: a scale of classes of sounds, universally ranked by “how loud,” or sonorous, the sounds in the class are (e.g., Cairns and Feinstein, 1982, Roca and Johnson, 1999).

In addition to the requirement that onset clusters exhibit a rising sonority profile, adjacent segments in an onset cluster must satisfy a minimum sonority distance. The minimal tolerable sonority distance varies with language. English onset clusters require a sonority distance of at least two degrees, based on the scale in Table 1. For example, the sonority distance between the

segments in the cluster /tl/ is the difference between the liquids and the obstruents on the scale (3 - 1 = 2), satisfying the minimal sonority distance requirement in English; /gv/, however, is not an acceptable onset in English because it violates the minimum distance requirement with a difference of 0 (e.g., Cairns and Feinstein, 1982; Roca and Johnson, 1999). Other languages are more permissive, tolerating flatter sonority profiles in the onset. For example, /gv/ is a permissible syllable onset in Russian, which allows sonority-plateauing, and even some sonority-falling, segments in syllable onsets (Ostapenko 2005; Berent et al., 2007).

Berent, Steriade, Lennertz, and Vaknin (2007) investigated whether English speakers are sensitive to varying sonority profiles of unattested syllable onsets. The findings imply that universal preferences for certain onset clusters exert a controlling influence on English speakers' perception of unattested onset clusters.

The experiments in the study involved monosyllabic nonce words containing onset clusters unattested in English. The clusters were grouped into three categories: onset clusters with small sonority rises (e.g. *bnif*); onset clusters with sonority plateaus (e.g. *bdif*); and onset clusters with sonority falls (e.g. *lbif*), in increasing degree of markedness.

In an experiment in which English speakers were tasked with determining whether auditory monosyllabic nonce words were identical to their disyllabic, epenthetic counterparts (e.g. *lbif* versus *lebif*), it was found that participants were more likely to classify nonce words with universally dispreferred onsets (e.g. *lbif*) as disyllabic, misperceiving the onset consonant sequences as their epenthetic counterparts (e.g. *lebif*)—but less likely to do so when exposed to onsets that are relatively preferred across languages (e.g. *bdif*). That is, English speakers recoded extremely marked clusters into unmarked, disyllabic counterparts (for example, the marked

monosyllabic input *lbif* would be recoded as *lebif*)—finding it less difficult to learn novel onset phonotactics from unmarked sonority-rising word-onset sequences than from novel marked sonority-plateauing sequences.

An additional study provided further evidence for the idea that universal grammatical preferences implicate constraints on language learning. The authors reasoned that a pattern of misperception in which a monosyllabic cluster is perceived as identical to its epenthetic analogue implies that marked onsets are equally likely to benefit from priming by their unmarked, epenthetic counterparts as from their identical forms. Participants were presented with two auditory stimuli—the *prime* and *target*—and were tasked with determining whether both exist in English in order to study whether the processing of the prime word would affect that of the target word. The results showed that epenthetic (e.g. *lebif-lbif*) and identity primes (e.g. *lbif-lbif*) exerted the same amount of influence on targets with falling sonority onsets.

Like Berent et al. (2007), Redford (2008) aimed to investigate whether unmarked patterns should be easier to learn than marked ones—if statistical language learning is constrained by the same factors that result in unmarked language patterns. The experimental design was similar to that of Berent et al. (2007) in measuring auditory perception of unfamiliar CC clusters whose sonority profiles were manipulated to model grammatical markedness constraints

In Redford's (2008) study, native English speakers first listened to naturally produced words beginning with sonority-rising and sonority-plateauing (i.e. marked) consonant clusters that do not occur in English (like *tlevat* or *bdevat*, respectively). Following this training phase, the participants listened to the same clusters word-medially (e.g. *vatlet* and *vabdet*) and were asked to syllabify each “word.” The participants tended to indicate two syllables for the marked

sequences (e.g. *vab.det*), suggesting that they recoded, or repaired, the word-initial marked clusters in the training phase (e.g. *bdevat* was recoded as *bedevat*). The results showed that listeners were better at learning novel sonority-rising onsets than novel sonority-plateauing ones, suggesting that there is a markedness effect on phonotactic learning.

Redford (2008) included a production component to investigate whether production factors constrain phonotactic learning. Participants' productions were collected and used in a subsequent syllabification task to determine whether the participants' coarticulatory patterns predicted their treatment of novel sonority-rising and sonority-plateauing clusters. The findings affirmed this: sonority-rising clusters were found to be more coarticulated than sonority-plateauing clusters—and were learned at a higher rate than novel-plateauing onsets.

Redford (2008) found that English speakers are sensitive to the markedness of unattested syllable onsets, and that universal preferences for certain onset clusters exert a controlling influence on English speakers' perception of unattested onset clusters. Overall, the results suggest that “the powerful effects of statistical learning are moderated by the perception-production loop in language.”

CHAPTER 3: HYPOTHESIS

The hypothesis in the present study holds that if it is possible to learn non-native phonotactics through brief recent production experience and if learning is constrained by universal markedness preferences, the rate at which clusters in a speech production task adhere to positional constraints should correspond to the markedness of the clusters.

Constraint adherence on the part of a given cluster is determined by comparing legal and illegal error rates for the cluster: the higher the illegal movement error rate, the weaker the adherence to a particular constraint. Following earlier definitions, movement errors are slips in which one of the eight clusters in a sequence is replaced by another cluster from the sequence. For example, if the target syllable is *drest*, but the participant produces *tlest*, the cluster /t/ erroneously moves to the onset of the intended syllable. This definition includes cutoff errors such as *drest* → *tl . . . drest*. When a cluster moves to the same position that it occupied in the original, or target, sequence, the slip is considered a legal movement error. For example, when a sequence as presented to the subject contains the syllables *skerk*, *drelg*, *gvevd*, and *tlest*, but the subject produces *skerk*, *drelg*, *gvevd*, and *drest*, the erroneously produced syllable, *drest*, contains a slipped /dr/ in the onset. In this case /dr/ has undergone legal movement, since it is constrained to the set of onset clusters. Legal movement errors obey the particular constraints governing the target cluster, as the slips preserve the cluster's position within a syllable; illegal movement errors, however, do not preserve the cluster's original syllable position, violating the constraints acting on the involved cluster. Continuing with the example target sequence above: if the subject produces *sterk*, *drelg*, *gvevd*, and *tlest*, the erroneously produced syllable, *sterk*, contains a

slipped /st/ in the onset. In this case /st/ has undergone illegal movement, since /st/ in this sequence appears in the coda of the target syllable.

If speakers are familiar with an unmarked cluster in the stimuli, a confound of prior exposure is created, introducing the possibility that learning was based to any degree on statistical properties of the clusters and precluding the interpretation that the results may reflect universal grammatical preferences. However, if speakers possess innate markedness preferences, such preferences should generalize to unattested structures. Accordingly, the present study isolates the effects of markedness from the influence of prior exposure by comparing rates of constraint adherence by clusters that are both unattested in specific syllable positions in English, with the expectation that an unmarked and unattested cluster will be involved in illegal movement errors at a lower rate than a marked unattested cluster.

3.1 Properties of the clusters and syllables

The hypothesis is a series of predictions concerning rates of different types of speech errors involving consonant clusters, elicited by having participants recite lists of CCVCC syllables in which some clusters are always onsets, some are always codas, and some are unrestricted in terms of position.

As a preliminary to presenting these predictions, the following describes the composition of the syllables presented to the participants, and various properties of the clusters themselves. The stimuli consisted of lists of sequences of four CCVCC syllables. Each sequence contained eight different clusters—/gv/, /tl/, /dr/, /sk/, /vd/, /lg/, /rk/, and /st/ (spelled in the stimuli as “gv,” “tl,” “dr,” “sk,” “vd,” “lg,” “rk,” and “st,” respectively)—with two clusters per syllable, one at

either edge of the syllable, surrounding the vowel “e.” Each cluster appeared once per sequence and each consonant necessarily appeared twice per sequence. The sequences contained all possible permutations of four CCVCC syllables under certain constraints that dictated which syllable edge a cluster could appear in.

Two experiments were carried out in the present study, identical in all respects with the exception of the nature of the positional constraints, or lack thereof, on /sk/ and /st/. In both experiments, /gv/, /tl/, /dr/, and /sk/ were always restricted to the onset position and /vd/, /lg/, /rk/, and /st/ to the coda position. In Experiment 2, however, /sk/ and /st/ were free to appear in either syllable edge. (The motivation for Experiment 2 is detailed further in the following sections of the current chapter.)

To equate for error opportunities among the clusters and individual consonants, the set of onset clusters and the set of coda clusters roughly paralleled each other in markedness and familiarity as well as the distribution of the individual consonants. The following characterizes the sounds in the stimuli in terms of sonority markedness and attestation in English (Table 2 illustrates the distribution of sounds in the two sets of clusters along these dimensions):

- /gv/ and /vd/ are sonority-plateauing and do not appear in English onsets or codas, respectively;
- /tl/ and /lg/ are sonority-rising and sonority-falling, respectively, and do not appear in English onsets or codas, respectively;¹

1. /tl/ onsets are still marked in English as sequences of a coronal stop followed by a coronal lateral (e.g. Leben, 1973). The current study, however, is concerned with markedness as determined by sonority, as discussed in Chapter 2. In this chapter and throughout, all statements regarding markedness refer specifically to markedness as determined by the Sonority Sequencing Principle, unless otherwise specified.

- /dr/ and /rk/ are sonority-rising and sonority-falling, respectively, with /dr/ attested in English as onset and /rk/ as coda;
- /sk/ and /st/ are permissible in both codas and onsets in English. Although /sk/ and /st/ are technically sonority plateauing, according to the definitions of the Sonority Sequencing Principle and the minimal distance parameter outlined in Chapter 2, /s/+obstruent clusters constitute an exception in English, being permissible at either syllable edge, and effectively function as single units for the purposes of this study. The special exceptional status of /sk/ and /st/ means that the parallelism or symmetry between the set of coda clusters and onset clusters is present in Experiment 2 as well as Experiment 1.

	Familiar	Unfamiliar
Unmarked by sonority	/dr/ (onset) /rk/ (coda) /sk/ (Experiment 1: onset; Experiment 2: onset and coda) /st/ (Experiment 1: coda; Experiment 2: onset and coda)	/tl/ (onset) /lg/ (coda)
Marked by sonority	*	/gv/ (onset) /vd/ (coda)

Table 2. Distribution of clusters by familiarity, markedness, and experiment-wide positional constraints. “Onset” or “coda” in the parentheses following a cluster refers to the syllable edge to which that cluster is restricted in the stimuli syllables in a particular experiment. For example, /sk/ is a grammatical and familiar cluster in English, and is restricted to the onset in Experiment 1, but appears in both onset and coda positions in Experiment 2. (The square containing “*” is empty, as the stimuli contained no familiar cluster that was marked by sonority in the position it appeared in.)

The symmetry between the set of onset clusters and the set of coda clusters is not perfect, however—most significantly in terms of sonority-related constraints, which in English are not in a perfect mirror-image relationship between onset and coda positions, though other types of asymmetries exist as well.² For example, the sequence /vd/ is only roughly polar to /gv/: although neither is attested in English as within-morpheme, within-syllable clusters, and each has an inappropriate sonority slope for its syllable position, /vd/ is not an uncommon sequence in English—but only when spanning two morphemes, as in the verb “roved,” the past tense of “rove.” During the experimental sessions, subjects were instructed to think of each syllable in the stimuli as an unfamiliar or foreign word describing a noun entity, in order to encourage the perception of syllables ending in “vd” as mono-morphemic.

Due to the imperfect parallelism between the set of onset and coda clusters, the following predictions concerning error types and rates apply to onset clusters only (and in fact this is the case with the bulk of the present study, including most of the results and discussion). That is, predictions for an onset cluster do not extend to form valid predictions for that cluster’s coda analogue. Parallel predictions would assume that, for example, /vd/ is dispreferred in codas over /lg/ in the same manner that /gv/ is dispreferred in onsets relative to /tl/—but that is not the case, and such a prediction would be inaccurate.

2. To illustrate the lack of parallelism between the sonority-related constraints governing syllable onsets and codas, consider the words “lamp” and “fact.” Although the Sonority Sequencing Principle states that the minimum acceptable distance between adjacent consonants in a syllable edge is two degrees, the coda clusters /mp/ and /kt/ have sonority distances of 1 and 0, respectively. However, even if we posit that the minimal sonority distance between adjacent segments in a coda may be as low as 0, consider that there are other clusters with a sonority distance of 1 or 0 that are *not* permissible in English, such as /tp/ (sonority distance 0) or /kn/ (sonority distance 1) (e.g., Cairns and Feinstein, 1982, Roca and Johnson, 1999).

3.2 Experiment 1

A cluster’s tendency to move to an illegal syllable edge in a speech error is contingent on a number of factors, summarized in Table 3. These constraints or features of attestation and markedness interact to determine the likelihood of a cluster’s landing in a particular syllable edge during a slip. Table 3 is an attempt to organize and quantify these factors in order to show the relative well-formedness of a slip that places the cluster in coda versus onset position. Since predictions will be phrased in terms of illegal errors, the table shows the cost for landing in a particular syllable edge —i.e. how “expensive” it is to slip to a particular position in the absence of constraints attracting the cluster to the site.

Cluster	Position	Attested in this position in English?	Experiment-wide constraint?	Unmarked by sonority in this position?	Cost for this position
gv	onset	*	✓	*	2
	coda	*	*	*	3
tl	onset	*	✓	✓	1
	coda	*	*	*	3
dr	onset	✓	✓	✓	0
	coda	*	*	*	3
sk	onset	✓	✓	✓	0
	coda	✓	*	✓	1

Table 3. Factors that determine the cost for movement to a particular syllable edge in Experiment 1. Values in the column “Position” refer to the potential landing site. The symbol “✓” represents the absence of a constraint on a given syllable edge, and “*” its absence. Each value in the last column, “Cost for this position,” is a tally of the “*”s in that value’s row.

The following describes the columns and values in Table 3.

- *“Position” column*: For each cluster, there are two values for position, onset and coda, which refer to potential slip landing sites.
- *“Attested in this position?” column*: A “✓” in this column indicates that the cluster does occur in a given position in English; a “*” indicates that the cluster does not appear in that position in that position in English—meaning that there is a cost for landing in that particular position. For example, since /gv/ does not appear in either position in English, both onset and coda values contain “*.” This models language-wide constraints.
- *“Experiment-wide constraint?” column*: A “✓” in this column indicates the presence of an experiment-wide constraint; a “*” indicates that there is a cost for landing in that particular position. For example, throughout the experiment, /gv/ is constrained to the onset only; accordingly, the onset value contains “✓,” but the coda value contains a “*.”
- *“Unmarked by sonority in this position?” column*: A “✓” in this column indicates that a given cluster is marked by sonority for the given syllable position; a “*” indicates the absence of such a constraint. For example, /gv/ is marked by sonority for onset and coda; accordingly, both onset and coda cells in this column contain “*.”
- *“Cost for this position” column*: The values in the final column quantify the cost for a given cluster to slip into a given syllable edge. The cost function is a simple additive process, where each item to be summed is a single unit, and all items have equal weight. More specifically, the cumulative cost for moving into a certain position is calculated by summing the number of “*”s present in that value’s row, since each “*” represents a single “unit” cost (in other words, the presupposition is that all constraints—attestation,

sonority, and experiment-wide—have equal weight) for landing in a particular syllable edge. In the case of /gv/, for example, there are two “*”s in the onset value and three “*”s in the coda value. Since the “*”s represent the cost for landing in that particular position, the implication is that it is more costly for /gv/ to land in the coda position rather than the onset position during a movement error. This makes sense, as the only constraint acting on /gv/ is the experiment-wide one restricting it to onsets. In contrast, consider the /tl/ row. It is similar to the /gv/ row in all respects except for the “✓” in the onset cell in the “Unmarked by sonority in this position?” column, meaning that /tl/, due to its sonority-rising profile, is constrained to the onset by universal sonority markedness constraints. Consequently, the cost for /tl/ to land in an onset position is 1, while the cost for landing in a coda position is 3, just as for /gv/. The implication is that it is “cheaper” for /tl/ to land in the onset position versus the coda position.

The specific questions addressed in the present study concern the legality of movement errors involving different types of consonant clusters under a variety of constraints. Comparing the relative illegal error rates for a pair of clusters, in which each cluster is operating under a different type constraint, allows for a comparison of the constraints’ relative strengths. Table 4 summarizes the predictions for relative rates of illegal movement errors for pairs of onset clusters.

The numbers in the first two columns of Table 4, “Cluster 1: Cost for onset vs. cost for coda” and “Cluster 2: Cost for onset vs. cost for coda,” refer to the last column of Table 3, which calculated the overall cost for a slip to a particular position. The last column, “Prediction: Cluster 1 vs. Cluster 2,” makes use of the first two columns to derive the comparisons. (The symbols

“>”, “<”, and “≈” indicate whether the first cluster is predicted to show a higher, lower, or equivalent illegal movement error rate to the second cluster. For example, “gv ≈ sk” indicates that the clusters /gv/ and /sk/ are predicted to exhibit equivalent illegal movement error rates.) Each prediction in the last column is derived by comparing the difference in movement costs to the onset and coda for each cluster.

Cluster 1: cost for onset vs. cost for coda	Cluster 2: cost for onset vs. cost for coda	Prediction: Cluster 1 vs. Cluster 2
gv: 2 vs. 3	tl: 1 vs. 3	gv > tl
gv: 2 vs. 3	dr: 0 vs. 3	gv > dr
gv: 2 vs. 3	sk: 0 vs. 1	gv ≈ sk
tl: 1 vs. 3	dr: 0 vs. 3	tl > dr
tl: 1 vs. 3	sk: 0 vs. 1	tl < sk
dr: 0 vs. 3	sk: 0 vs. 1	dr < sk

Table 4. Determining which of a pair of clusters would find it more costly to slip into the coda position rather than the onset position in Experiment 1. The first two columns refer to the last column of Table 3. (The symbols “>” and “<” indicate which of a pair of clusters is predicted to show a higher illegal movement error rate and the symbol “≈” indicates that both clusters are predicted to show equivalent illegal movement error rates. For example, “gv > tl” is shorthand for “the rate of illegal movement errors involving /gv/ is higher than the rate of illegal movement errors involving /tl/.”)

To state the derivation procedure more rigorously: assuming an additive process for calculating cost, with all constraints (sonority, experiment-wide, and attestation) equally weighed, determining which of a pair of clusters has highest illegal movement error rate can be evaluated by (a) calculating the difference in cost for landing in the legal syllable edge (i.e. the

onset for the set of onset clusters) versus landing in the illegal syllable edge (i.e. the coda for the set of onset clusters) and (b) comparing the result of this calculation for each cluster in the pair. In other words, the question is: in a comparison of two onset clusters, which one would find it more “expensive” to slip into the coda position—the illegal syllable edge—rather than preserve its position in the onset during a slip?

For example, consider the prediction concerning /sk/ and /dr/. Movement errors involving /sk/ should occur more often as (illegal) codas than movement errors involving /dr/, as the /sk/ restriction to the onset is an experiment-wide constraint, while the /dr/ restriction to onsets is due to its sonority profile as well. Therefore, the illegal error rate of /sk/ should be higher than that of /dr/. In terms of the table, /dr/ is drawn to onset versus coda by 3; but sk is drawn to onset versus coda by 1: hence, $dr < sk$. The cluster /gv/, however, is drawn to the onset by 1, as is /sk/—therefore the prediction is that the illegal movement rates for these clusters should be about the same: $gv \approx sk$. The remaining predictions are derived in a similar manner.

To verify the congruence between the key prediction for the two unattested clusters /gv/ and /tl/ as derived by Table 4 and the prediction as derived by reasoning about hypothetical relationships among positional constraint adherence rates at various levels of generality, the following reviews both derivations.

If the markedness of an unfamiliar cluster has no bearing on the ability to learn positional constraints, the illegal error rates for accidental productions involving /gv/ would not be significantly different from those involving /tl/; that is, the rate at which /gv/ moved to coda position during a slip would not be significantly different than the rate at which /tl/ moved to coda position during a slip. However, if markedness does constrain phonotactic learning, the

constraint adherence rate for an unfamiliar cluster would be influenced by whether the cluster is marked by sonority in English. Since the plateauing sonority profile of the onset cluster /gv/ is not acceptable in English syllable onsets due to the sonority distance requirement for the language, /gv/ should exhibit a lower rate of constraint adherence than /tl/, which is sonority-rising and therefore not marked by sonority in onset position in English.

As rates of positional constraint adherence and illegal movement are in indirect correspondence, this prediction that /tl/ will demonstrate a greater sensitivity to the SSP constraint accords with the comparison $gv > tl$ in Table 4, though the latter is derived with reference to numerical costs for landing in a particular syllable edge. The first two columns in Table 4 make use of the information in Table 3, which lists each cluster's cost for slipping into coda position versus that for slipping into onset position. In the case of /gv/, the last column showed the cost for landing in an onset position versus landing in a coda position. The difference between the tallied “*”s was 1, since the only constraint acting on /gv/ is the experiment-wide one restricting it to onsets. The difference in cost for landing in an onset position versus landing in a coda position for /tl/, however, was greater (by 2), since /tl/ is under the universal SSP markedness constraint as well as the experiment-wide constraint restricting it to the onset. In other words, compared to the cost for slipping to coda position, /tl/ finds it “cheaper” to move into the onset position than does /gv/, as the cost difference between moving to the two syllable edges is smaller for the latter cluster. Hence the prediction in the last column: /gv/ will show a higher rate of illegal errors than /tl/.

3.3 Experiment 2

Experiment 2 differs from Experiment 1 only in that in Experiment 2 /sk/ and /st/ are no longer restricted to the onset and coda, respectively—each appears in the onset half the time and in the coda half the time, meaning that the evidence for a novel phonotactic rule concerning /sk/ is weaker (or nonexistent). In other words, in Experiment 2, /sk/ is governed by local constraints only; in Experiment 1, however, /sk/ is governed by the experiment-wide constraint as well.

Table 5 shows the factors that determine the cost for movement to a particular syllable edge in both Experiment 1 and Experiment 2, building on Table 3 (values in shaded cells apply to Experiment 2 only; values in all other cells apply to both Experiment 1 and Experiment 2). The fact that only /sk/ (and /st/) constraints differ from Experiment 1 is reflected in the final row.

Cluster	Position	Attested in this position in English?	Experiment-wide constraint?	Unmarked by sonority in this position?	Cost for this position	
gv	onset	*	✓	*	2	
	coda	*	*	*	3	
tl	onset	*	✓	✓	1	
	coda	*	*	*	3	
dr	onset	✓	✓	✓	0	
	coda	*	*	*	3	
sk	onset	✓	✓	×	0	0
	coda	✓	*	×	1	0

Table 5. Factors that determine the cost for movement to a particular syllable edge in Experiment 1 and Experiment 2. Values in shaded cells apply to Experiment 2 only (all other values apply to both experiments). Values in the column “Position” refer to the potential landing site. The symbol “✓” represents the absence of a constraint on a given syllable edge, and “*” or “×” represent its absence. Each value in the last column, “Cost for this position,” is a tally of the “*”s in that value’s row.

Note that the system of representation used in Table 5 expands on that used in Table 3 with the addition of the symbol “X”. This expansion is needed to account for the case when a cluster—namely, /sk/—is not governed by an experiment-wide constraint but incurs no cost for movement to either syllable edge. In Experiment 2, /sk/ is not experimentally constrained, making “✓” an inappropriate choice for both onset and coda values in the “Experiment-wide constraint?” column—but “✱” is inappropriate as well, as the presence of this symbol would increment the value calculated in the last column in Table 5. In the case of Experiment 1, the “✱” in the /sk/ row in Table 3 reflects a unit of cost associated with movement to the coda position due to the presence of the experiment-wide constraint restricting /sk/ to the other syllable edge. In Experiment 2, however, an absence of a constraint restricting /sk/ to any one syllable edge does not imply a cost for moving to the opposite edge. Therefore, a third symbol is needed to indicate that movement to a certain syllable edge incurs no cost, and this is represented with “X.”

Ultimately, however, the finer details of this system of representation—at least in this specific case—may be moot. In both Experiment 1 and 2, the total cost for /sk/ to slip to onset position is the same as the cost to slip to coda position, making the difference between the two values is zero in both experiments. This number is eventually used in the predictions that compare relative rates of illegal movement errors for pairs of clusters, meaning that the values of the numbers in the final column in Table 5 are not necessarily of interest in and of themselves.

All but one prediction for relative costs for moving to different syllable edges (last column) in Experiment 2 remain the same as in Experiment 1, as can be seen in Table 6. The prediction for /gv/ and /sk/ differs: in Experiment 2 /sk/ is not drawn more than /gv/ to onset

position, as in Experiment 1; here, the cost for moving to onset position is the same as the cost for moving to coda position.

Cluster 1: Cost for onset vs. cost for coda	Cluster 2: Cost for onset vs. cost for coda	Prediction: Cluster 1 vs. Cluster 2
gv: 2 vs. 3	tl: 1 vs. 3	gv > tl
gv: 2 vs. 3	dr: 0 vs. 3	gv > dr
gv: 2 vs. 3	sk: 0 vs. 1 0 vs. 0	gv ≈ sk gv < sk
tl: 1 vs. 3	dr: 0 vs. 3	tl > dr
tl: 1 vs. 3	sk: 0 vs. 1 0 vs. 0	tl < sk tl < sk
dr: 0 vs. 3	sk: 0 vs. 1 0 vs. 0	dr < sk dr < sk

Table 6. Determining which of a pair of clusters would find it more costly to slip into the coda position rather than the onset position in Experiment 1 and Experiment 2. Values in shaded cells apply to Experiment 2 only (all other values apply to both experiments).

In Experiment 1, /sk/ and /gv/ were predicted to show similar rates of illegal movement, or constraint violations. In Experiment 2, however, /sk/ is predicted to move to an illegal syllable edge at a higher rate than /gv/. Movement errors involving /sk/ should tend to codas, rather than the “legal” onset syllable edge, at a higher rate than /gv/, as /sk/ is restricted to the onset by local constraints only—in contrast to /gv/ which is restricted to onsets due to an experiment-wide constraint as well. Therefore, the illegal error rate of /sk/ should be higher than that of /gv/. In Table 6, moving /gv/ to onset position, or the legal syllable edge, is less expensive than moving

/gv/ to coda position, whereas moving /sk/ to onset position costs the same as moving to coda position, meaning that /sk/ should exhibit more illegal movement errors than /gv/, hence $sk > gv$.

The predictions for the remaining cluster pairs in Experiment 2 are the same as in Experiment 1, although in some cases the reasoning differs, namely in the case of pairs that involved /sk/. In both experiments, /sk/ was predicted to move illegally at a higher rate than /tl/, in Experiment 1 due to its being governed by the theoretically weaker experiment-wide constraint when compared to the constraints acting on /tl/ (which was constrained by its sonority profile as well), but in Experiment 2 due to being governed by local constraints only.

In Experiment 1, a comparison of the illegal movement error rates between /dr/ and /sk/ shows that movement errors involving /sk/ tend to the illegal syllable edge at a higher rate than /dr/, demonstrating the dominance of the language-wide constraint over the experiment-wide constraint. Unlike in Experiment 1, which restricts /sk/ to the onset (and /st/ to the coda), in Experiment 2 /sk/ and /st/ each appear in the onset half the time and in the coda half the time, allowing for a simulation of local positional constraints that are not obscured by experimental constraints. Consequently, a comparison of illegal error rates for /dr/ and /sk/ in Experiment 2 amounts to a comparison of language-wide constraints and local positional constraints and, since these are at opposite ends of the breadth-of-constraint continuum as described by Dell et al. (2000), the prediction is that the /sk/ illegal error rate would be higher than the /dr/ illegal error rate.

Although the data gathered in Experiment 1 alone is sufficient to answer the primary research question concerned with the effects of the universal markedness constraint on the acquisition of non-native phonotactic patterns, the experiment does not offer a test of whether the

experiment-wide constraint is learned since all clusters are fixed. The cleanest test of the experiment-wide constraint would compare error rates for onset clusters that differ only in terms of positional restrictions throughout the experiment—that is, the ideal comparison would involve a cluster that is restricted to one syllable edge throughout the experiment with a cluster that appears in either syllable edge.

Therefore, since in Experiment 2 the onset cluster /sk/ is not under an experiment-wide constraint, it would ideally be compared with another onset cluster in Experiment 2 that, unlike /sk/, is fixed, but has the same status as /sk/ in terms of sonority markedness and attestation in English. No such cluster exists in Experiment 2. (This can be seen in Table 5, which shows that in both experiments there is no pair of clusters for which the error patterns would differentiate the experiment-wide and the language-wide constraints.)

The effects of learning the experiment-wide constraint can still be revealed, however, by comparing the constraint adherence rate on the part of /sk/ in Experiment 1 with the constraint adherence rate on the part of /sk/ in Experiment 2.

An illegal movement error rate involving /sk/ in Experiment 2 that is greater than that of /sk/ in Experiment 1 would indicate that subjects had indeed learned the experiment-wide constraints in Experiment 1. If, on the other hand, the rate of /sk/ illegal movement errors in Experiment 2 is not greater than that of /sk/ in Experiment 1, the implication would be that rates of constraint adherence (or the metric used to evaluate constraint adherence) did not reflect the learning of positional constraints—invalidating a significant methodological premise of the study. The prediction that follows holds that /sk/ should show a higher illegal movement error rate in Experiment 2 than it would in Experiment 1.

3.4 Ranking all constraints

Although ultimately the predictions of primary interest to the current study concern the unattested clusters, considering predictions for every possible pair permutation is interesting as it allows for multiple comparisons of a variety of constraints along the breadth-of-constraint continuum.

Using the transitive property it is possible to derive a single statement ordering all four onset clusters by their predicted illegal error rates in both experiments. The transitive property holds that if the rate of illegal movement errors on the part of cluster 1 is greater than the rate of illegal movement errors on the part of cluster 2, and if the rate of illegal movement errors on the part of cluster 2 is greater than the rate of illegal movement errors on the part of cluster 3, then the rate of illegal movement errors on the part of cluster 1 is greater than the rate of illegal movement errors on the part of cluster 3. Applying the transitive property to the Experiment 1 predictions in Table 4 derives the following single statement ranking the strength of constraint adherence in increasing order from left to right (or, equivalently, ranking the rate of illegal movement errors in decreasing order from left to right):

$$sk \approx gv > tl > dr$$

The expression states that /sk/ and /gv/ should exhibit similar rates of illegal movement errors, while /tl/'s illegal movement error rate should be lower, and /dr/'s illegal movement error rate lower still. That /sk/ and /gv/ exhibit similar rates of constraint adherence accords with the fact that both are under the experiment-wide positional constraint. The remaining rankings can be understood with reference to the particular constraint that is revealed in a particular comparison. For example, that /tl/ exhibits a higher rate of constraint adherence than /gv/ or /sk/

reveals the effect of the well-formedness constraint restricting /tl/ to the onset—which exerts an influence beyond that of the local and experiment-wide constraints, which /tl/, /gv/, and /sk/ are all under. Similarly, that constraints involving the sonority-rising clusters in the onset (/tl/ and /dr/) should be adhered to at a higher rate than those involving the more marked sonority-plateauing cluster /gv/ accords with the fact that both of the former are under the universal SSP constraint restricting them to the onset.

As the prediction for /gv/ and /sk/ in Experiment 2 changes to /sk/ > /gv/ from /sk/ ≈ /gv/, applying the transitive property to the new predictions derives the following statement:

$$sk > gv > tl > dr$$

In other words, whereas the Experiment 1 ranking stated that /sk/ and /gv/ should exhibit similar rates of illegal movement errors, the Experiment 2 ranking shows that /sk/ should undergo illegal movement errors at a higher rate than /gv/.

The Experiment 2 design allows for the separation of the experiment-wide constraints from that of the local constraints, resulting in the new prediction. Although Experiment 1 allowed for a test of the effects of markedness on errors, its design did not allow for a test of the breadth-of-constraint hypothesis, since every cluster in the stimuli is fixed with respect to syllable edge; in Experiment 2, however, the experiment-wide constraint on /sk/ is removed, allowing an evaluation of the syllable position effect, which, as the narrowest, or weakest, constraint on the breadth-of-constraint continuum, should be adhered to at the lowest rate.

Both statements developed above ranking clusters in terms of the strength of the constraint(s) governing them—and thus the cost models developed above to predict relative constraint adherence among the onset clusters—predict that the onset cluster for which an illegal

move is the costliest is /dr/. That is, /dr/ is ranked as having the highest constraint adherence rate of all onset clusters, including /tl/—meaning that the language-wide constraint acting on /dr/ has an effect beyond that of markedness. However, if the sonority constraint is the broadest or most general—as a putative markedness universal—among all the constraints acting on the onset clusters, then it should be obeyed at a higher rate than language-wide constraints. If the results conform to the predictions of the cost models developed for Experiments 1 and 2, the idea that universal markedness constraints are at the most general end of the breadth-of-constraint continuum would be called into question.

CHAPTER 4: METHOD

4.1 Participants

Thirty-four participants were recruited from the community and compensated with either \$10 in cash or entry into a raffle drawing for \$50. All participants were at least 18 years of age, with no speech or hearing deficits. All participants were native speakers of American English, with no significant exposure to languages containing any of the clusters in this study that are meant to be unfamiliar to the speaker.

Thirteen subjects participated in Experiment 1 and eleven in Experiment 2. However, the data from five participants was not used—three in Experiment 1 and two in Experiment 2—making the total number of subjects for Experiment 1 and 2 nine each. Three subjects were unable to perform the task in the experiment by being unable to keep pace with the metronome or to produce the unfamiliar clusters; two subjects (one in each experimental group), exhibited so few errors of all types, that their performance with the unfamiliar clusters was equivalent to their performance with the familiar clusters.

An additional ten subjects participated in a pilot study held prior to Experiments 1 and 2, conducted in order to determine a facet of the procedure (this and additional details concerning the pilot experiment are discussed in the following sections). The results and discussion do not consider data from the pilot study.

4.2 Procedure

Participants completed two primary tasks: first, they were trained to pronounce onset /gv/ and onset /tl/, following which they recited syllables containing these and other sounds.

In the training phase of the experiment, participants were coached in articulating two unfamiliar clusters: /tl/, which is sonority-rising and so unmarked by sonority as a syllable onset, and /gv/, which is sonority-plateauing and so marked by sonority as a syllable onset. The subjects were iteratively trained with flashcards and recitation drills until they were able to satisfactorily articulate each cluster sixteen times in succession, as judged by the experimenter.

During the production task, participants were recorded with a standing microphone inside a sound-attenuated booth using a Marantz solid-state recorder and a Grace Design pre-amplifier. Following training, participants were seated in front of a computer screen located inside the booth and instructed to read aloud sequences of syllables displayed on the computer screen and in other details of the upcoming procedure. Prior to beginning recording, participants were led in reciting several practice sequences in order to gain familiarity with the experimental task and the inventory of syllables.

Each of the 96 or 64 sets of sequences of four syllables to be recited were displayed on the computer screen on a single slide in a Microsoft PowerPoint presentation, as shown in Figure 1, which depicts a slide with the sequence “a gvelg, a drest, a skerk, a tlevd.” The orthography was straightforward, each syllable spelled as it appears in Tables 7 and 8.

As participants were to recite each sequence four times, each sequence appeared four times per slide. Subjects read the sequences on each screen, producing one syllable per beat in time with a metronome (broadcast through headphones worn by the participant throughout the

experiment) that began playing upon slide advancement. Subjects chose when to move on to the next set of syllables (continuing on to the following slide by a mouse click or keyboard button press) and were encouraged to advance through the slides as rapidly as possible.

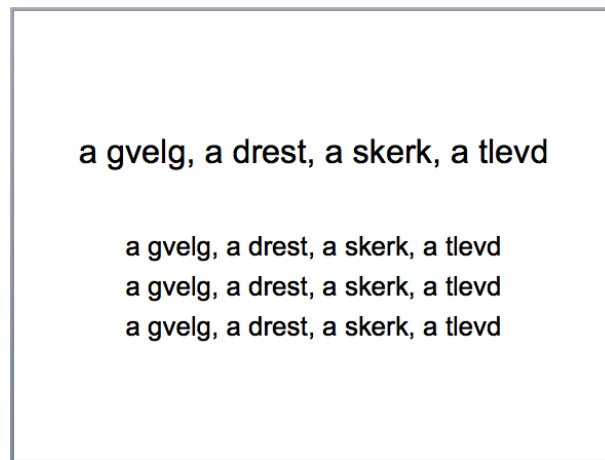


Figure 1. One of the slides presented to the participant during the production task.

The first sequence of each set of four was intended as practice and the top line of each slide was set in a larger typeface to emphasize this. The practice sequence was recited at a pace of 45 beats per minute, a lower rate than that for the other three sequences. The slower pace allowed for the subject to become familiar with the sequence and was not included in the data set.

To determine the exact rate for the faster rate at which participants recited the sequences presented to them, a pilot experiment was conducted. Using data from ten subjects, it was found that a rate of 125 beats per minute was too rapid to yield meaningful results—that is, errors at this rate may not reveal learning, but may reflect, for example, a participant's ability to deal with tongue twisters or to speak rapidly for a prolonged period. Additionally, the productions at 125

bpm were extremely difficult to transcribe. The reliability of error coding was quite poor for the recordings at the faster rate, with coder agreement at 68.8%, as compared to 90.3% for the data recited at the lower rate in Experiments 1 and 2.³ As the 125 bpm rate proved ineffective, the metronome rate was lowered for Experiment 1 and 2, to 90 bpm.⁴

4.3 Stimuli

The particulars of a structure's sonority profile classify it as marked or unmarked for the onset position within a syllable. Therefore, manipulating the sonority profile of a structure allows for a simulation of the markedness constraint in a reading task. Chapter 3 described various properties of the clusters and syllables in the stimuli; the following describes the composition and presentation of sequences that constitute the stimuli.

3. Agreement between the author and another coder was evaluated by comparing the transcriptions of an overlapping 10% (1,152/11,520 syllables) of the syllables recited at the faster rate. Both coders agreed there was no error on 601 of 1152 syllables transcribed; of the remaining syllables, the coders agreed on the presence and type of error for 192 syllables, making the overall coding agreement rate: $(601 + 192) / 1152 = 68.8\%$. Agreement for Experiments 1 and 2 was calculated from 2,112 transcribed syllables (constituting an overlapping 11% of all transcribed syllables). Both coders agreed there was no error on 1,288 syllables and agreed on the presence and type of error for 619 syllables, making the overall agreement rate $(1288 + 619) / 2112 = 90.3\%$.

4. Dell et al. (2000) set the metronome rate for their experiments at 2.53 seconds per syllable, or about 152 beats per minute. However, as the sequences in the present study are not only longer but also more difficult to produce than those used by Dell and colleagues, it stands to reason that participants would require more time—and exert more effort—to recite the same number of sequences. To compensate for the increased difficulty, I increased the amount of time allotted to each syllable, resulting in the lower metronome rate that was initially piloted (125 bpm), and in the even lower rate used in Experiments 1 and 2 (90 bpm).

Participants recited 96 or 64 sets of four identical sequences, each sequence containing four CCVCC nonsense syllables selected from an inventory of 16 syllable tokens in Experiment 1 (see Table 7) or 23 syllable tokens in Experiment 2 (see Table 8). Each subject was presented with $96 \times 4 = 384$ syllables in Experiment 1 and $64 \times 4 = 256$ syllables in Experiment 2.

The first 17 of 34 participants recited 96 sets, following Dell et al. (2000). However, the difficult consonant clusters presented a greater production challenge compared to the simpler CVC syllables used by Dell and his colleagues. Subjects in the present experiment fatigued towards the end of the experiment session, with a corresponding increase in errors. Consequently, data from the 64 sets only were analyzed for the first 17 participants; for the remaining participants, the number of sets was reduced to 64.⁵

Each sequence as well as the order of the sequences was pseudo-randomly generated such that each sequence contained one instance of each of the four onset clusters and one instance of each of the four coda clusters. (The complete sets of onset and coda clusters are as described above in Chapter 3.) In both the pilot study and Experiment 1, each cluster's position

5. In order to elicit meaningful speech error data from participants, untainted by fatigue or boredom, Dell et al. (2000) presumably settled on 96 as the ideal balance between (a) the minimum number of sequences per daily session needed to establish clear patterns with enough instances of each type of syllable to make implicit learning possible and to provide sufficient opportunities for movement errors to make for a large enough sample for statistically significant results, and (b) the maximum number of sets a participant could tolerate.

However, the parameters that determine this balance are different in the present experiment, as the syllables in the present stimuli demand more effort and time to produce than the simpler CVC syllables in Dell et al. (2000). As the stimuli in the present experiment consisted of fewer syllable types, it follows that fewer syllables—and fewer sequences—are sufficient to establish clear patterns, with enough instances to make (implicit) learning possible and to provide enough opportunities for movement errors to make for a large enough sample to derive statistically significant results.

within the syllable was artificially constrained to one of the syllable edges: /tl/, /gv/, /dr/, /sk/ were constrained to the onset and /lg/, /vd/, /rk/, /st/ to the coda. The stimuli for Experiment 2 were identical to those of Experiment 1, with the exception that /sk/ and /st/ were not restricted to onsets and codas, respectively, but each appeared an equal number of times in each syllable edge.

skerk	skelg	skevd	skest
drerk	drelg	drevd	drest
gverk	gvelg	gvevd	gvest
tlerk	tlelg	tlevd	tlest

Table 7. The lexicon of 16 syllables defined by the Experiment 1 constraints.

skerk	skelg	skevd	skest
drerk	drelg	drevd	drest
gverk	gvelg	gvevd	gvest
tlerk	tlelg	tlevd	tlest
sterk	stelg	stevd	stesk
dresk	gvesk	tesk	

Table 8. The lexicon of 23 syllables defined by the Experiment 2 constraints.

Each cluster appeared once per sequence and each consonant appeared twice per sequence—once in a coda cluster and once in an onset cluster. The vowel was always “e.” The sequences contained all permutations of four CCVCC syllables under the constraints present in that particular experiment.

Each sequence of four syllables in the reading task was described as a series of nonsense words—specifically, as a listing of alien creatures with necessarily unfamiliar (i.e. alien) names, in order to encourage the perception of each syllable as a noun entity for several reasons. First,

the syllables were presented as nouns (described to the participants as names of alien creatures to account for the unfamiliarity of the words) in order to discourage the perception of syllables ending in /vd/ as verbs in the past tense, as word-final /vd/ is a familiar consonant sequence to English speakers, as in “roved,” the past tense of “rove,” for example. Furthermore, the sequences were designed to look like lists of indefinite nouns—each syllable was preceded by “a” and all but the last syllable followed by a comma, e.g. “a tlerk, a gvest, a drelg, a skevd”—so that each intervening “a” provided a consistent opportunity for recovery between syllables (in a more efficient and symmetric way than would “the”), serving to separate what would otherwise be adjacent consonant clusters. Additionally, presenting the sequences as lists was meant to elicit the corresponding intonation in an effort to ensure that all CCVCC syllables received equal stress so that this and related or consequent phenomena do not become confounding variables.⁶

6. The prosody that characterizes the recital of a list of items provided for easier detection of syllable boundaries, which was helpful in terms of accuracy, ease, and speed of transcription when coding the data.

CHAPTER 5: RESULTS AND DISCUSSION

5.1 Coding and reliability

Speech errors in the recordings were transcribed by the author and a second individual who received specific instructions in how to transcribe the recordings but was otherwise uninformed of the study objectives. The transcribed data was input to a Python script for error identification, categorization and rate calculations. In addition to tracking cluster repair and movement errors, the script classified errors into additional categories such as (single) consonant exchanges and vowel replacements, though these are not made use of in the analysis. The program also kept track of omitted syllables for calculation of error rates; it often occurred that the number of attempted syllables differed from the number of syllables presented to the participants. The output was spot-checked for accuracy.

The reliability of error coding was good. Coder agreement between the author and the other coder was evaluated by comparing an overlapped 11% of the transcribed syllables recited in Experiment 1 and Experiment 2, using a procedure similar to that in Dell et al. (2000). Both coders agreed there was no error on 1,288 of 2,112 syllables transcribed. Of those syllables that both coders agreed were in error, the coders agreed on the nature of the error for 619 syllables, making the overall agreement rate $(1288+619)/2112 = 90.3\%$.

5.2 Movement errors

In both experiments, the relative illegal movement error rate predictions crucial to the hypothesis that participants will learn novel, non-native constraints, obeying the markedness constraints at the highest rate, were upheld.

Table 9 and Figures 2 and 3 describe the frequencies and rates of all movement and cluster repair errors produced in Experiment 1, in which nine participants attempted a total of 6,595 out of 6,912 syllables (4 syllables x 3 repetitions x 64 sequences x 9 subjects); in Experiment 2, another nine participants attempted 6,553 out of 6,912 syllables. Table 10 and Figures 4 and 5 describe the frequencies and rates of the errors of interest produced in Experiment 2.

	Cluster	Movement errors		Cluster repair errors	
		Legal	Illegal	Consonant Deletion	Vowel epenthesis
Restricted to onsets	gv	6 (60.0%)	4 (40.0%)	45	365
	tl	6 (100.0%)	0 (0.0%)	81	96
	dr	40 (100.0%)	0 (0.0%)	40	16
	sk	17 (60.7%)	11 (39.3%)	0	0
Restricted to codas	vd	25 (100.0%)	0 (0.0%)	209	6
	lg	3 (100.0%)	0 (0.0%)	109	2
	rk	9 (100.0%)	0 (0.0%)	29	0
	st	18 (100.0%)	0 (0.0%)	80	0

Table 9. Experiment 1 results: movement errors (legal and illegal) and cluster repair errors (consonant deletion and vowel epenthesis) for all clusters.

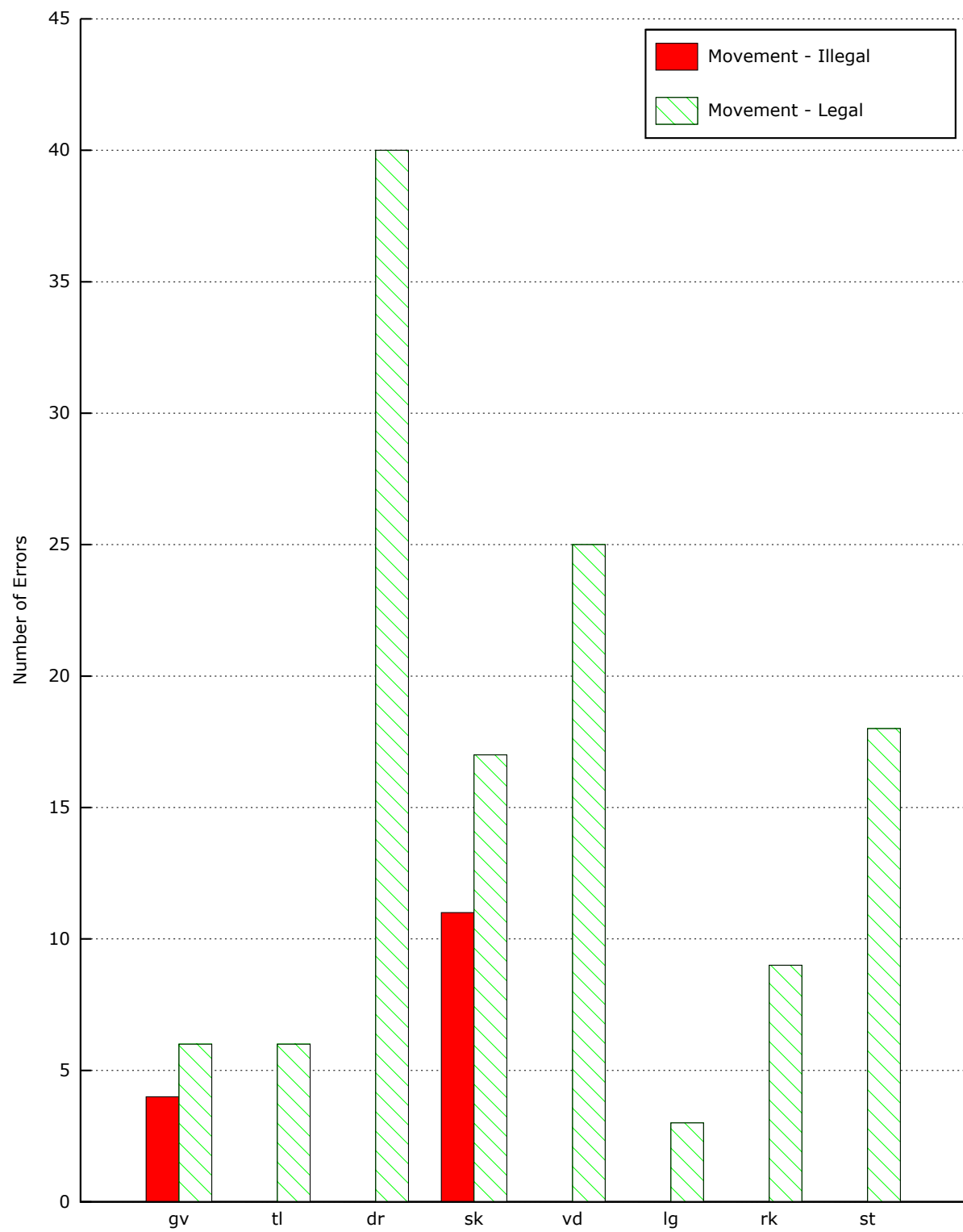


Figure 2. Experiment 1 results: legal and illegal movement errors for all clusters.

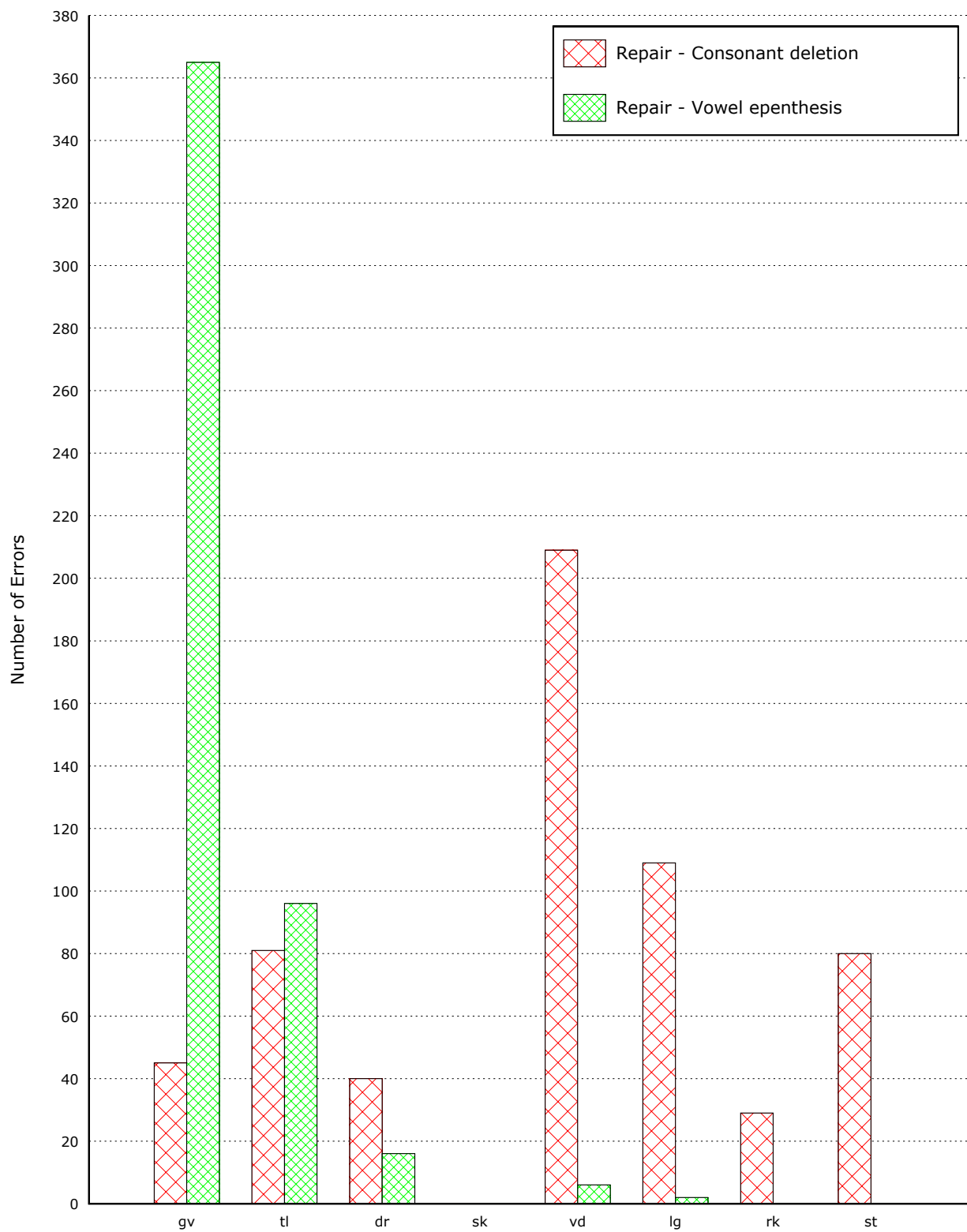


Figure 3. Experiment 1 results: cluster repair errors (consonant deletion and vowel epenthesis) for all clusters.

	Cluster	Movement errors		Cluster repair errors	
		Legal	Illegal	Consonant Deletion	Vowel epenthesis
Restricted to onsets	gv	6 (60.0%)	4 (40.0%)	14	420
	tl	2 (100.0%)	0 (0.0%)	8	200
	dr	14 (100.0%)	0 (0.0%)	7	79
Free	sk	7 (6.8%)	96 (93.2%)	47	0
Restricted to codas	vd	20 (100.0%)	0 (0.0%)	59	0
	lg	3 (100.0%)	0 (0.0%)	78	0
	rk	0 (100.0%)	0 (0.0%)	25	0
Free	st	13 (11.6%)	99 (88.4%)	76	0

Table 10. Experiment 2 results: movement errors (legal and illegal) and cluster repair errors (consonant deletion and vowel epenthesis) for all clusters.

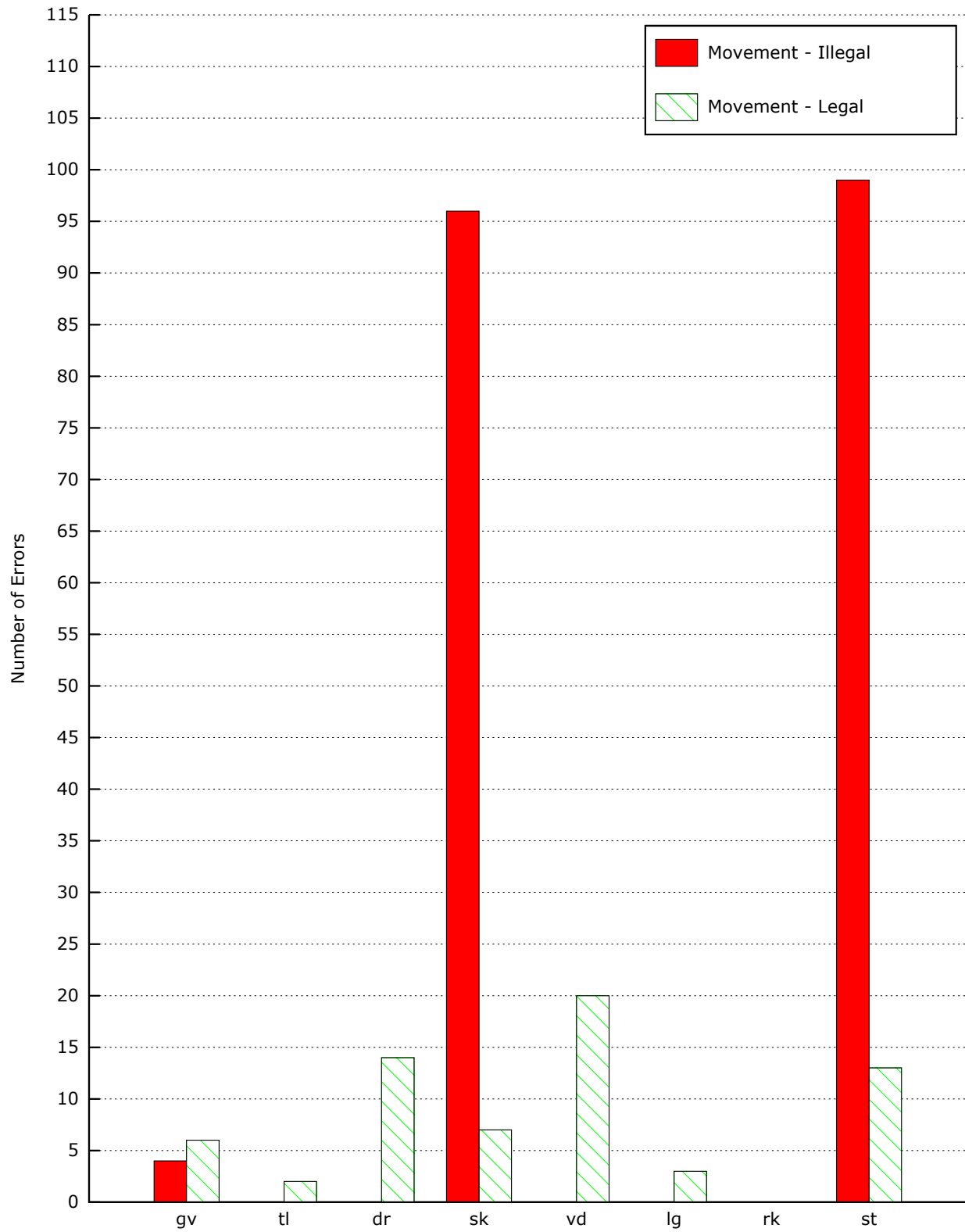


Figure 4. Experiment 2 results: legal and illegal movement errors for all clusters.

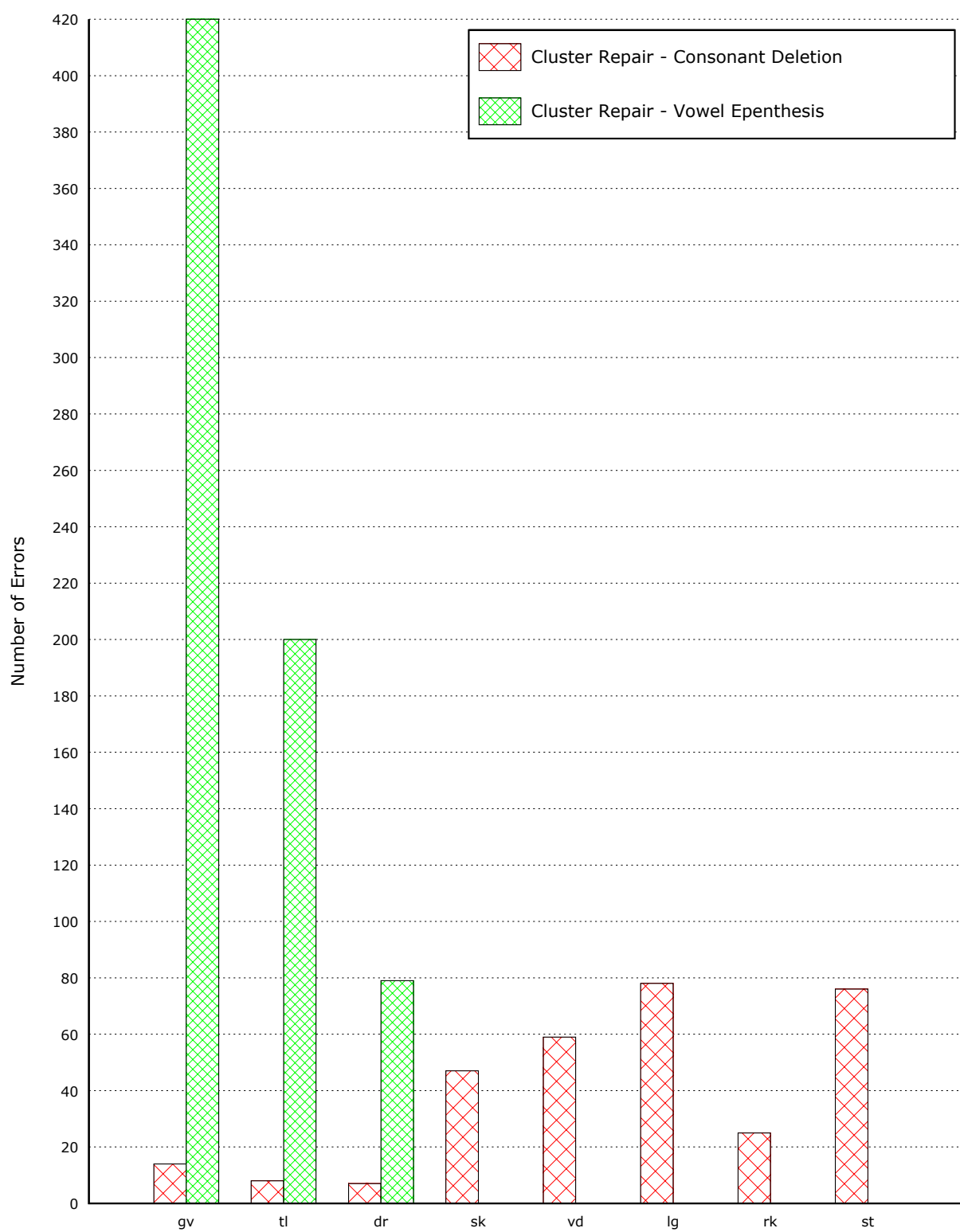


Figure 5. Experiment 2 results: cluster repair errors (consonant deletion and vowel epenthesis) for all clusters.

5.2.1 Experiment 1

Table 11 and Figure 6 describe the frequencies and rates of illegal and legal movement errors produced in Experiment 1. Out of 6,595 attempted syllables, a total of 139 movement errors were identified, a 2.1% error rate per syllable. Table 12 summarizes the predictions and results for rates of illegal movement errors for pairs of onset clusters in Experiment 1.

The key prediction in the current study concerned the two unattested onset clusters: /gv/ was predicted to show a larger illegal movement rate than /tl/ and this was displayed in the results. Of 10 movement errors involving /gv/, 4 were illegal, while all 6 movement errors involving /tl/ were legal, confirming the hypothesis that, if markedness does constrain phonotactic learning, the relative performance rates of learning novel clusters would be influenced by cluster sonority distance, or by the universal SSP constraint restricting clusters with sonority-rising profiles to the onset.

Cluster	Legal	Illegal
gv	6 (60.0%)	4 (40.0%)
tl	6 (100.0%)	0 (0.0%)
dr	40 (100.0%)	0 (0.0%)
sk	17 (60.7%)	11 (39.3%)

Table 11. Experiment 1 onset clusters: legal and illegal movement errors.

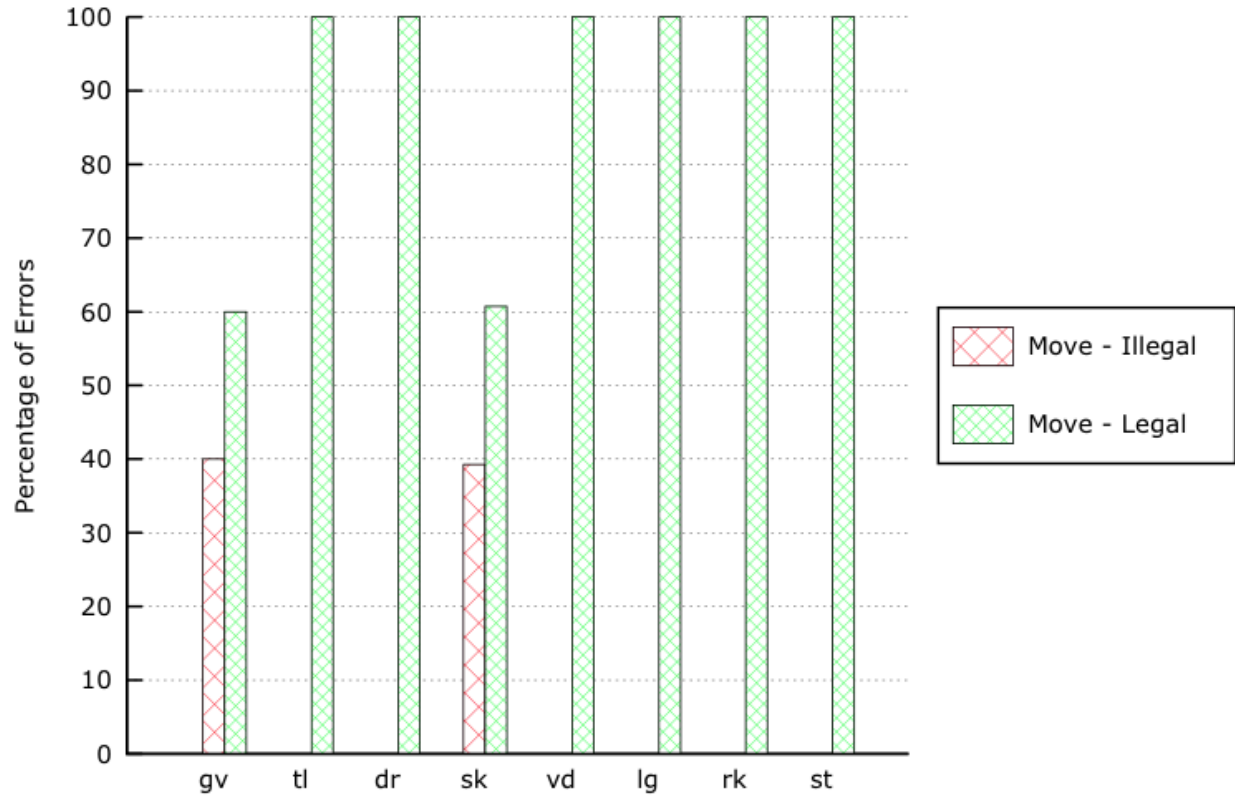


Figure 6. Percentages of illegal and legal movement rates for all clusters in Experiment 1.

Predictions	Results
gv > tl	gv > tl
gv > dr	gv > dr
gv ≈ sk	gv ≈ sk (40.0% vs. 39.3%)
tl > dr	Not confirmed (tl: 0%; dr: 0%)
tl < sk	tl < sk
dr < sk	dr < sk

Table 12. Illegal movement error rates for pairs of onset clusters in Experiment 1: predictions and results.

Of the 40 movement errors involving /dr/, 100% were legal, exhibiting the phonotactic regularity effect. Of the 28 movement errors involving /sk/, 17 were legal and the remaining 11 were illegal, meaning that the experiment-wide constraint was upheld 60.7% of the time. This accords with the prediction that movement errors in Experiment 1 involving /sk/ should tend to codas, rather than the legal onset syllable edge, at a higher rate than /dr/ would and demonstrates that adherence to the language-wide constraint was not simply adherence or reduction to the experiment-wide constraint.

The remaining predictions involving /sk/ were confirmed as well: /sk/, which was under the experiment-wide constraint only, showed a higher illegal movement error rate (at 39.3%) than did /tl/ (which was constrained by its sonority profile as well as the experiment), whose slips preserved position 100% of the time; additionally, /gv/ and /sk/ showed approximately equal illegal error rates, at 40.0% and 39.3% illegal movement, respectively.

The cluster /dr/ was predicted to show a higher adherence rate than /gv/ and /tl/ both. The results confirmed the former prediction: of 10 movement errors involving /gv/, 40% were illegal, while /dr/ showed a 0% illegal movement rate, with all 40 movement errors involving /dr/ slipping to the legal syllable edge. The latter prediction concerning the two sonority-rising onsets clusters /tl/ and /dr/—that the unattested cluster /tl/ would show a higher illegal movement rate than /dr/—was not confirmed, however, since both clusters preserved position during slips 100% of the time.

5.2.2 Experiment 2

Table 13 and Figure 7 describe the frequencies and rates of illegal and legal movement errors produced in Experiment 2. Out of 6,553 attempted syllables, 264 movement errors were identified, a 4.0% error rate per syllable. Table 14 summarizes predictions for rates of illegal movement errors for pair of onset clusters in Experiment 2.

The prediction central to the hypothesis, and the reasoning behind it, was the same in both experiments: if sonority-based markedness constrains phonotactic learning, /tl/, or the onset cluster with the sonority-rising profile, should exhibit a higher constraint adherence rate than /gv/, whose sonority-plateauing profile marks it in English syllable onsets. This prediction was confirmed in Experiment 2 as well as Experiment 1: of 10 movement errors involving /gv/, 4 were illegal, while both movement errors involving /tl/ slipped to the legal syllable edge.

Cluster	Legal	Illegal
gv	6 (60.0%)	4 (40.0%)
tl	2 (100.0%)	0 (0.0%)
dr	14 (100.0%)	0 (0.0%)
sk	7 (6.8%)	96 (93.2%)

Table 13. Experiment 2 onset clusters: legal and illegal movement errors.

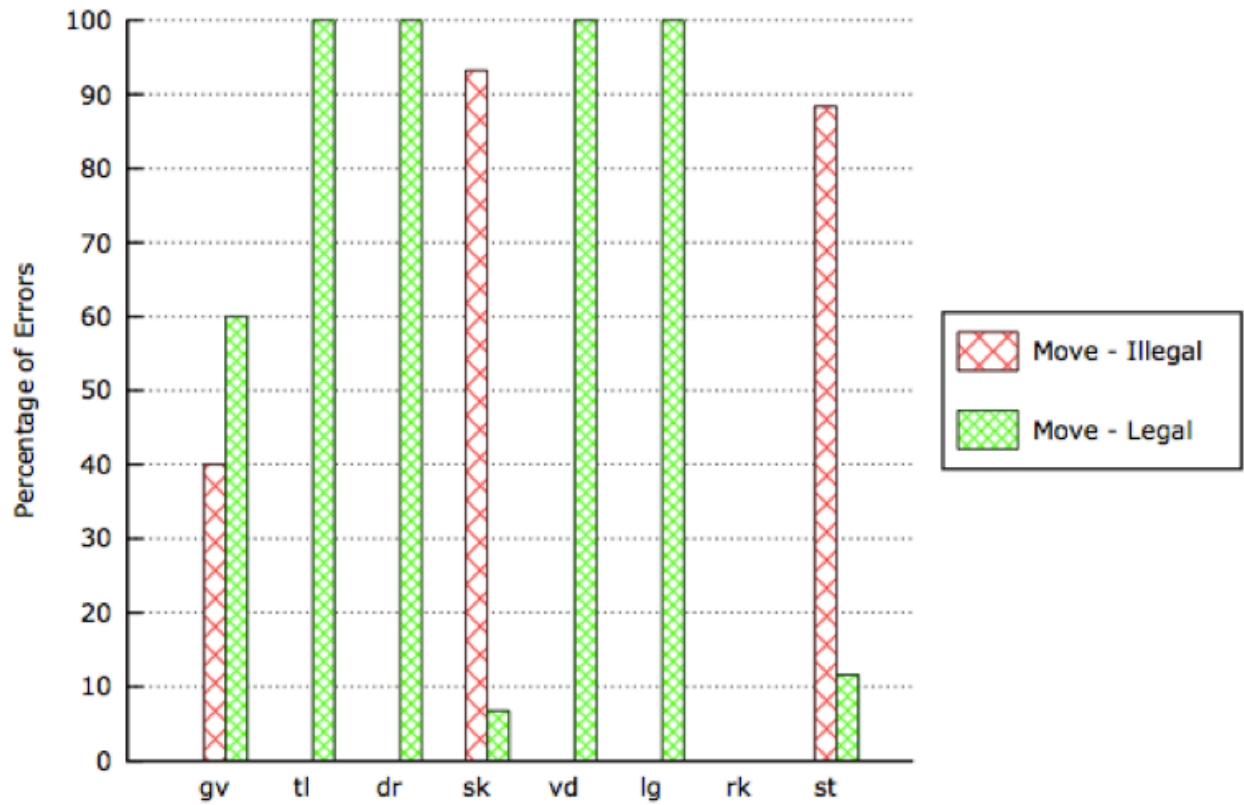


Figure 7. Percentages of illegal and legal movement rates for all clusters in Experiment 2.

Predictions	Results
gv > tl	gv > tl
gv > dr	gv > dr
gv < sk	gv < sk
tl > dr	Not confirmed (tl: 0%; dr: 0%)
tl < sk	tl < sk
dr < sk	dr < sk

Table 14. Illegal movement error rates for pairs of onset clusters in Experiment 2: predictions and results.

Like /tʌ/, /dɹ/ is not marked in syllable onsets, which, along with the language-wide constraint, underlies the prediction that /dɹ/ will show a higher constraint adherence than /gʌ/. This was confirmed, as all 14 movement errors involving /dɹ/ slipped to the legal syllable edge, but /gʌ/ moved illegally at a rate of 40%.

While Experiment 1 predicted that /gʌ/ and /sk/ would exhibit similar rates of illegal movement errors, the fact that /sk/ is unconstrained in Experiment 2 means that /sk/ should show more illegal movement errors than /gʌ/. Experiment 2 results confirm this, as the /gʌ/ illegal error rate, at 40.0%, was lower than that of /sk/, which moved to an illegal syllable edge 96 out of 103 times, at a rate of 93.2%.

Although the constraints governing /sk/ in Experiment 2 were different from those governing /sk/ in Experiment 1, the predictions comparing the /sk/ illegal movement error rate to that of /dɹ/ and that of /tʌ/ remained the same. /sk/ was anticipated to disobey constraints at a higher rate than both /dɹ/ and /tʌ/ in both experiments because the constraints governing /sk/ were the weakest—though those constraints were experiment-wide in the case of Experiment 1 but local in the case of Experiment 2. Both predictions were upheld in the results, with /sk/ showing a 93.2% illegal movement error rate compared with /dɹ/’s 0%, demonstrating that the language-wide constraint exerts an influence beyond that of local constraints.

As in Experiment 1, the prediction concerning the two sonority-rising onsets clusters /tʌ/ and /dɹ/ in Experiment 2 was that the unattested cluster /tʌ/ would show a higher illegal movement rate than /dɹ/. As in Experiment 1, this was not confirmed in Experiment 2, since both clusters preserved position during slips 100% of the time.

5.2.3 Discussion

The stimuli in Experiment 2 were designed to determine whether the speech error data in Experiment 1 was indicative of experiment-wide constraint acquisition in Experiment 1. As there is no longer an experiment-wide restriction on /sk/ and /st/ in Experiment 2—each appear in the onset half the time and in the coda half the time—the evidence for a novel phonotactic rule concerning /sk/ is weaker (or nonexistent), meaning that /sk/ should show a higher illegal movement error rate in Experiment 2 than in Experiment 1. The results showed that /sk/ was involved in illegal movement errors at a lower rate in Experiment 1 than in Experiment 2, demonstrating that speakers were responding to the /sk/ pattern established in Experiment 1. Figure 8 compares the rate of illegal movement errors in Experiment 1 and Experiment 2, for all clusters. The key difference is the jump in the rate of illegal movement errors involving /sk/: from 39.3% in Experiment 1 to 93.2%—more than double—in Experiment 2.

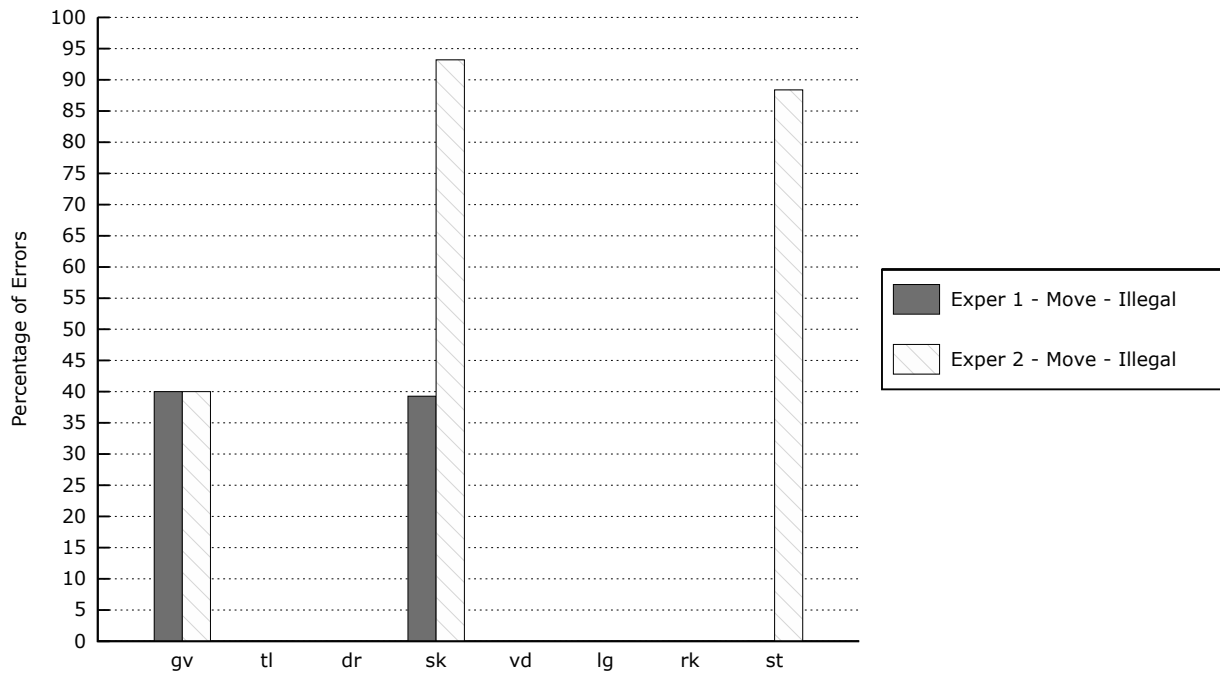


Figure 8. Comparing illegal movement error rates in Experiment 1 and Experiment 2.

The predictions for relative rates of constraint adherence for pairs of clusters as summarized in Tables 12 and 14 are formulated such that application of the transitive property to the rankings derives a single hierarchy ordering rates of illegal movement errors, or the rates of constraint adherence involving every onset cluster. Chapter 3 discussed how applying the transitive property to the predictions derived a single statement ordering all four onset clusters by their predicted illegal error rates, or, equivalently, a single statement ranking various constraints by strength. Both derived hierarchies rank the rate of illegal movement errors involving /dr/ lower than that of /tl/, suggesting that the language-wide constraint is the strongest, or broadest, of those presented to the participants. This prediction, however, questions the notion that the putatively universal sonority markedness constraint is the strongest among all the constraints acting on the onset clusters.

The results do not offer a firm conclusion concerning the /tl, dr/ ranking. The data show that there was no difference between the rates of adherence to the universal sonority-based markedness constraint governing /dr/ and the language-wide constraint governing /tl/; while this indicates that the findings do not support the idea that the markedness constraint has an impact beyond that of the language-wide constraint, the fact that both constraints were absolute (in both experiments 100% of all /tl/ and /dr/ movement errors were legal) suggest a ceiling effect—the test may not be sensitive enough to reveal a difference.

Of the clusters that were always restricted to the onset in both experiments—/gv/, /tl/, and /dr/—the unfamiliar clusters /gv/ and /tl/ exhibited a surprisingly low rate of legal movement errors. In Experiment 1, /gv/ and /tl/ each legally moved 6 times (compare to 40 /dr/ legal movement errors), accounting for only 11.5% each of all legal movement errors involving /tl/,

/gv/, and /dr/. In Experiment 2, /gv/ and /tl/ legally moved 6 and 2 times (compare to /dr/'s 14 legal movement errors), respectively, the former accounting for 27.3% and the latter for 9.1% of all legal movement errors involving the onset clusters under experiment-wide constraints.

A possible explanation for /gv/ and /tl/'s relatively low legal movement error rates involves the idea that the sheer difficulty in articulating the unfamiliar clusters served to draw a disproportionately large amount of attention to the unfamiliar clusters in particular, and the increased effort served to make it less likely that an unfamiliar cluster would be moved to any syllable edge.

The notion of extra attention directed to unfamiliar segments exists in the literature: Whalen and Dell (2006) found that in an experiment in which native English speakers received training in onset [ŋ] and recited sequences including syllables with [ŋ] onsets, out of syllables with correctly-produced syllable onsets, those with [ŋ] onsets were more likely to have erroneous codas than syllables with any other correctly produced onset. Whalen and Dell conjectured that extra attention directed to the production of an [ŋ] onset may have led to the additional coda errors. In the present study, syllables with /tl/ and /gv/ onsets were more likely to have errors in the coda than syllables with any other correctly-produced onset (9.4% versus 6.5% of syllables, respectively). It may be that these additional coda errors were a result of increased attention to the production of the unfamiliar onsets specifically.

5.3 Cluster repair errors

The specific predictions concerned the nature and frequencies of movement errors involving intact clusters. However, the hypothesis that participants will learn novel, non-native

constraints, but subject to a markedness effect, justifies some investigation into cluster repair errors as well, as these are certain to occur in a task that requires production of marked structures.

When required to produce utterances containing marked consonant clusters, English speakers tend to repair these clusters in speech, most commonly achieving this with vowel epenthesis or consonant deletion. (In the present study, the majority of participants' speech errors were cluster repair errors employing vowel epenthesis and consonant deletion nearly exclusively.)

Vowel epenthesis—or the intercession of a vowel between adjacent sounds—is one of a class of marked cluster repair strategies that optimize contrast between adjacent segments; consonant deletion—which serves to simplify a complex sequence—sacrifices contrast (e.g. Davidson 2006; Berent et al. 2007; Pitt 1998; Alderate 2003; Hume and Johnson 2001). For example, if the target syllable is *gvest* but the participant produced *gəvest*, the cluster /gv/ was repaired by vowel epenthesis; if the participant produced *gves*, the cluster /st/ was repaired by consonant deletion.

Comparing the rate of cluster repair with the rate of movement errors in Experiment 1 and Experiment 2 reveals how typological markedness interacts with grammatical preferences. Figures 9 and 10 show the total number of movement errors together with the total number of cluster repair errors to illustrate the correspondences produced in Experiment 1 and Experiment 2.

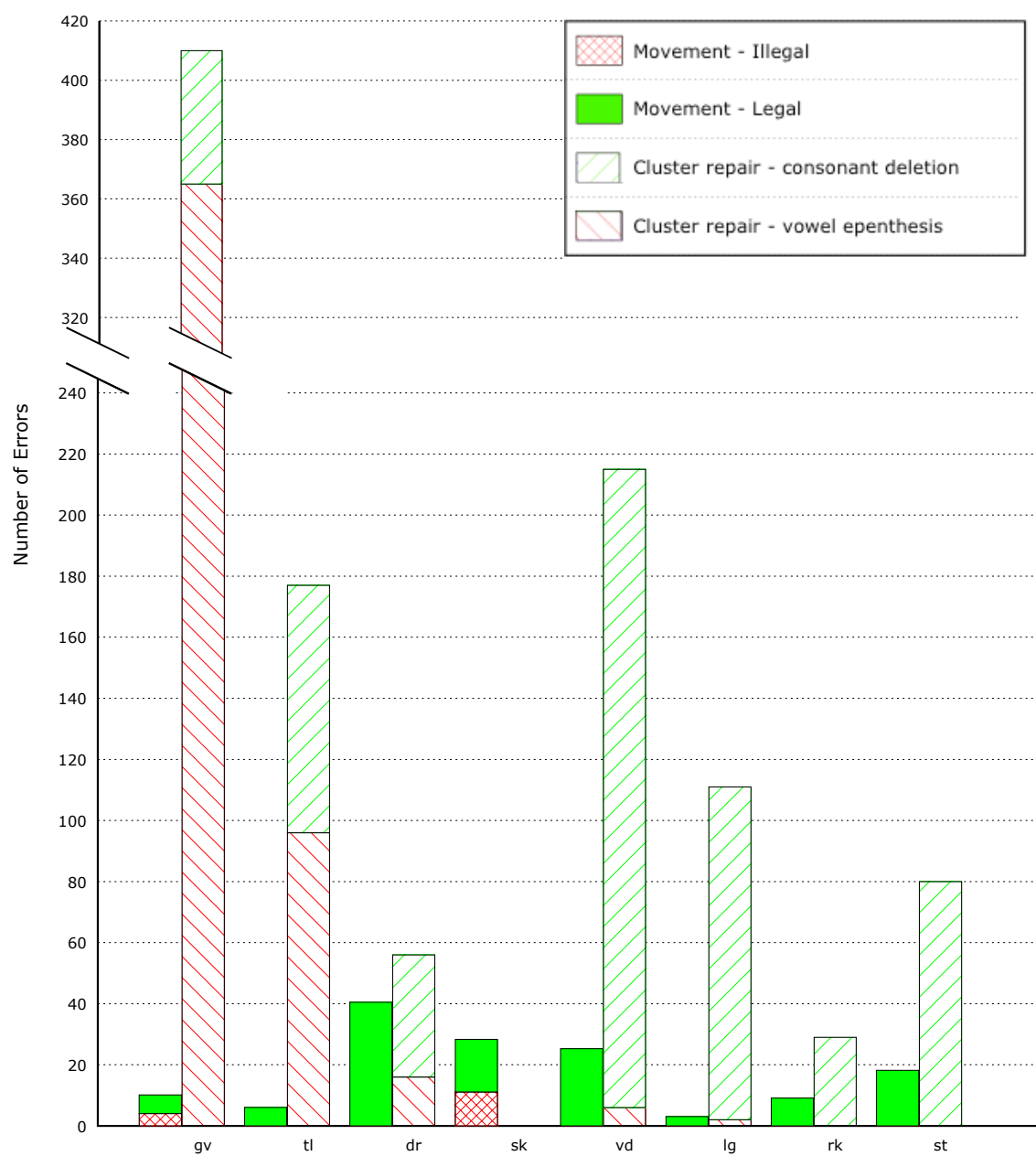


Figure 9. Comparing the number of movement errors with the number of cluster repair errors produced in Experiment 1.

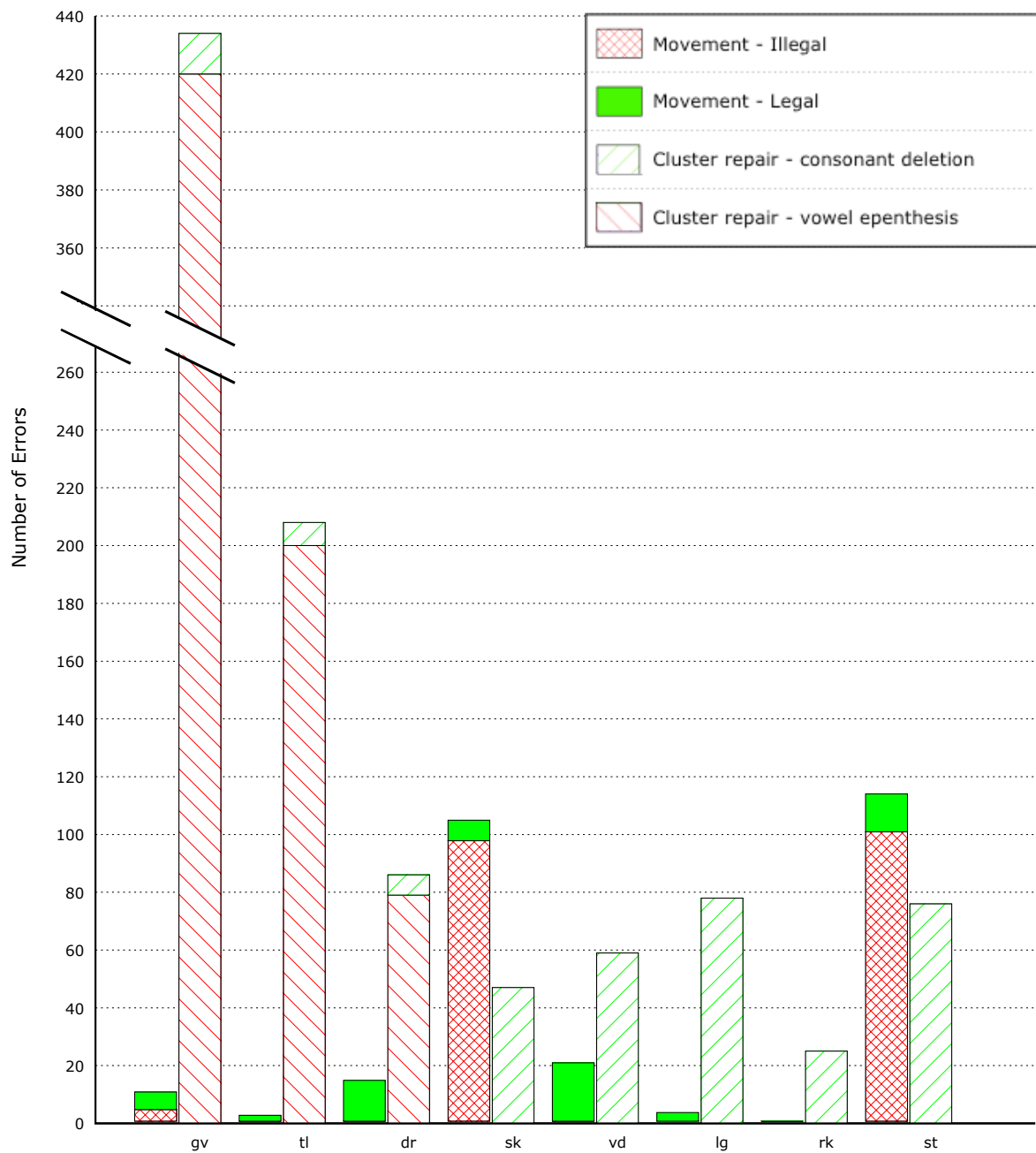


Figure 10. Comparing the number of movement errors with the number of cluster repair errors produced in Experiment 2.

Table 15 and Figure 11 describe the frequencies of cluster repair errors produced in Experiment 1. Out of 6,595 attempted syllables, a total of 1,078 cluster repair errors were identified, a 16.3% error rate per syllable. Table 16 and Figure 12 describe the frequencies of cluster repair errors produced in Experiment 2. Out of 6,553 attempted syllables, 1,013 cluster repair errors were identified, for an error rate of 15.5%.

In Experiment 1, /gv/ was repaired a total of 410 times, more than twice as much as /tl/ at 177, accounting for 38.0% and 16.4%, respectively, of all cluster repair errors. In Experiment 2 /gv/ was repaired a total of 434 times, more than twice as much as /tl/ at 208, accounting for 42.8% and 20.5%, respectively, of all cluster repair errors.

Cluster	Consonant deletion	Vowel epenthesis	Total cluster repair
gv	45	365	410
tl	81	96	177
dr	40	16	56
sk	0	0	0
vd	209	6	215
lg	109	2	111
rk	29	0	29
st	80	0	80

Table 15. Experiment 1: total number of errors for two types of cluster repair.

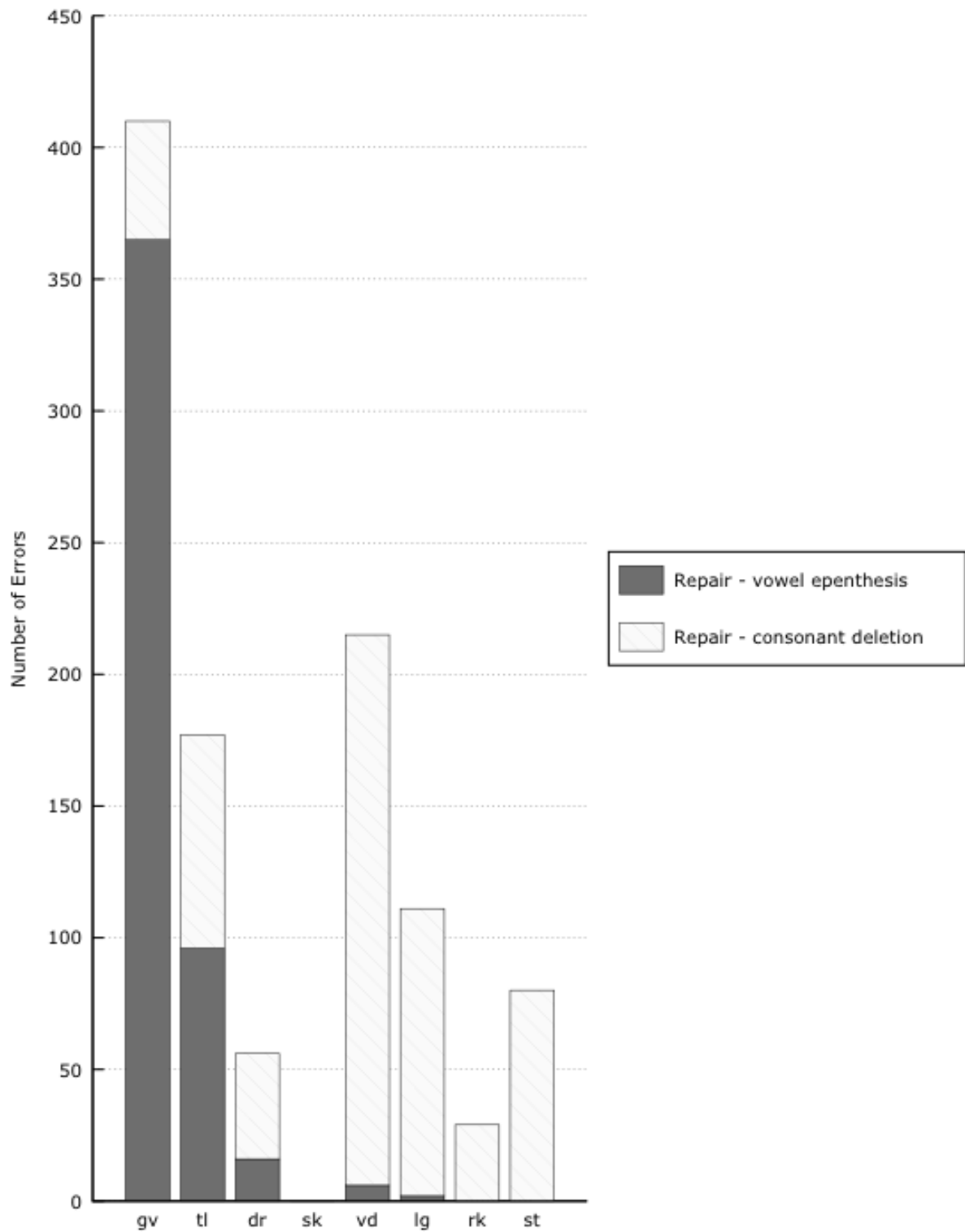


Figure 11. Number of errors for two types of cluster repair in Experiment 1.

Cluster	Consonant deletion	Vowel epenthesis	Total cluster repair
gv	14	420	434
tl	8	200	208
dr	7	79	86
sk	47	0	47
vd	59	0	59
lg	78	0	78
rk	25	0	25
st	76	0	76

Table 16. Summarizing results for Experiment 2. Totals for two types of cluster repair.

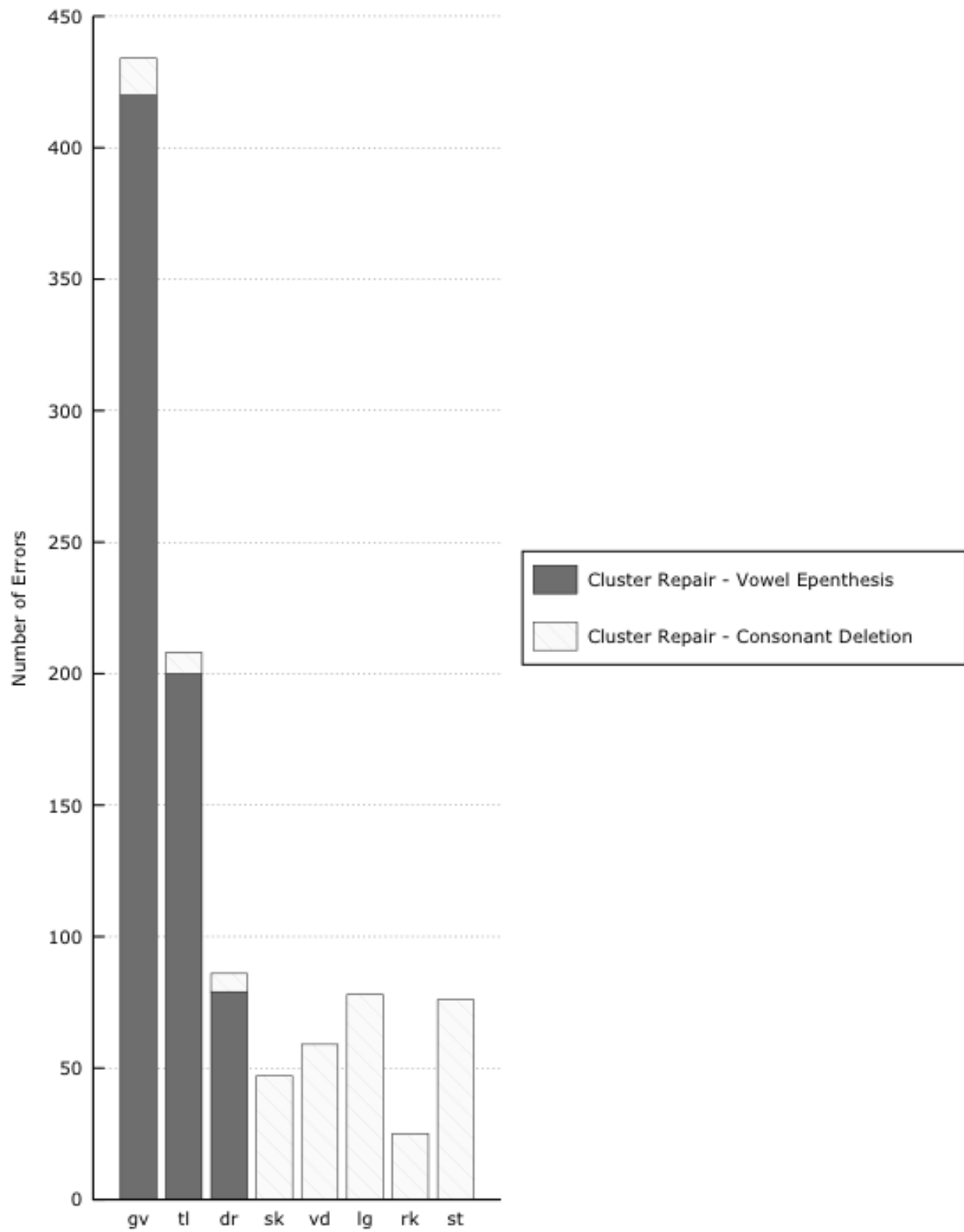


Figure 12. Number of errors for two types of cluster repair in Experiment 2.

If English speakers are sensitive to the markedness of unfamiliar clusters, subjects' cluster-repairing speech errors should show accuracy as inversely related to markedness; that is, the rate of cluster repair for a particular cluster directly corresponds to its markedness, specifically to whether the cluster's sonority profile is allowed in English onsets). The results of both experiments accord with the expectation that, of the unfamiliar clusters, the marked structure violating the Sonority Sequencing Principle—the sonority-plateauing /gv/—should undergo cluster repair at a higher rate than the unfamiliar, but unmarked cluster—the sonority-rising cluster /tl/.

That both /tl/ and /gv/ undergo repair, with /gv/ undergoing repair at a higher rate, reflects the link between grammatical and typological, or distributional, markedness, and accords with Greenberg's 1978 survey of word onsets, which found that clusters with large sonority rises, such as /tl/, are more frequent in syllable onsets (83% of the sampled data) than are sonority-plateauing onsets (49% of the sample).

It is curious that the clusters that are grammatical and frequent in English —/sk/, /st/, /dr/, and /rk/—underwent any kind of repair at all. These clusters accounted for 15.3% of all cluster repair errors in Experiment 1 and 23.1% in Experiment 2. A possible motivation for repairing the attested clusters may involve the need to maintain some kind of consistent rhythm throughout a sequence in which other clusters were repaired as well.

CHAPTER 6: CONCLUSION

The main research question in the current study is concerned with the effects of the universal markedness constraint on the acquisition of non-native phonotactic patterns, namely: will participants in a speech production task demonstrate that they learned recently encountered phonotactic constraints involving unfamiliar consonant clusters and that this learning was subject to a markedness effect?

In the literature, experiments in which participants produce sounds under artificial phonotactic constraints show that speakers can learn new speech patterns following only brief production experience, even when these patterns involve sequences unattested in the participants' native languages (e.g., Dell et al., 2000; Taylor and Houghton, 2005; Whalen & Dell, 2006). If markedness (in terms of the universal Sonority Sequencing Principle) constrains learning, novel unmarked patterns present in recent productions should be easier to learn relative to novel marked patterns.

Experiments to investigate the relative strengths of constraints along a breadth-of-constraint continuum ranging from the local to the language-wide have made use of elicited speech errors in production tasks that include novel patterns to show that constraints are obeyed at rates corresponding to the level of generality of the constraint. That is, the segments under the most specific, or local, constraints undergo illegal movement errors (or, slips that do not preserve the segment's position in the target syllable, thereby disobeying—or, not learning—the positional constraint) at the highest rate; the segments governed by the more general language-wide constraints undergo illegal movement errors at the lowest rate; and the segments under recently encountered, or experiment-wide, constraints are involved in illegal movement errors at a rate

that falls between the rates associated with the local and language-wide constraints (e.g. Dell et al., 2000).

If the Sonority Sequencing Principle constitutes the strongest or broadest constraint—as a putative markedness universal—among all the constraints acting on the onset clusters in the present study, it should be obeyed at the highest rate. That is, movement errors involving the unmarked clusters in a speech production task should obey artificial positional constraints at a higher rate than movement errors involving the marked clusters.

As comparing error rates involving a familiar unmarked cluster and an unfamiliar marked cluster presents a potential confound of prior exposure, the present study compared the performances of clusters that are both unattested in specific syllable positions in English—if speakers possess innate markedness preferences, such preferences should generalize to unattested structures.

In the present study, native speakers of English were recorded reciting syllables that included the unattested clusters /tɫ/ and /ɡv/ as well as other familiar consonant clusters under phonotactics constraints of varying generality. The key prediction was that, of the two unattested clusters, /ɡv/ (which is marked for syllable onsets by sonority and not tolerated in English in onset position) would show a higher illegal movement rate—or, a lower rate of constraint adherence—than /tɫ/ (which is not marked by sonority for onset position). This prediction was confirmed, with constraint adherence rates demonstrating that learning of novel phonotactic constraints was subject to a markedness effect.

The following is an overview of the present study, beginning with a description of the procedure and stimuli and followed by a summary of the specific predictions and results.

6.1 Summary

In two experiments, eighteen adult speakers of American English participated in two tasks. In the training phase of both experiments, subjects were trained to articulate the unfamiliar clusters /tl/ and /gv/ as syllable onsets; in the production phase the participants read aloud sets of sequences of syllables, presented as lists of unfamiliar words, in time to a metronome. Each syllable contained an “e” surrounded by two of eight unique clusters under a variety of positional constraints. In both experiments, the clusters /gv/, /tl/, /dr/ appeared in the onset position only and /vd/, /lg/, /rk/ appeared in the coda position only. The two experiments were identical in all respects with the exception of the positional constraints governing /sk/ and /st/: in Experiment 1, the remaining clusters, /sk/ and /st/, appeared only in the onset and coda positions, respectively; in Experiment 2, both /sk/ and /st/ appeared in the onset and coda positions an equal number of times.

Although the data gathered in Experiment 1 alone was sufficient to answer the primary research question concerned with the acquisition of non-native phonotactic patterns, Experiment 2 was designed to test whether the experiment-wide constraint was learned. As the sequences in Experiment 2 do not provide evidence of a consistent, or experiment-wide, positional pattern involving /sk/, if the illegal movement error rate involving /sk/ in Experiment 2 were found to be equivalent to that in Experiment 1, the implication would be that rates of constraint adherence did not reflect the learning of positional constraints. A comparison of /sk/ illegal errors in Experiment 1 and Experiment 2 showed that subjects were indeed learning the experimental constraint: the rate at which /sk/ was involved in legal movement increased from 39.3% in Experiment 1 to 93.2%—more than double—in Experiment 2.

The predictions for relative rates of constraint adherence for pairs of onset clusters were the same in both Experiment 1 and Experiment 2, with the exception of the comparison between /gv/ and /sk/, as this was affected by the stimuli change in Experiment 2. In Experiment 1, the prediction was that the clusters /gv/ and /sk/ would exhibit similar rates of illegal movement errors; in Experiment 2, however, the prediction concerning these clusters was that /sk/ would show more illegal movement errors than /gv/. Both predictions were confirmed in the results: in Experiment 1, /sk/ and /gv/ showed approximately equal illegal movement error rates, at 40.0% and 39.3%, respectively; in Experiment 2, the /gv/ illegal error rate, at 40.0%, was lower than that of the /sk/, at 93.2%.

The cluster /gv/ was predicted to show a higher illegal movement rate, demonstrating a lower rate of constraint adherence, than /dr/ in both experiments. This was confirmed in the results: in each experiment, /gv/ moved to the coda, or the illegal syllable edge, 40.0% of the time, while /dr/ never did so, always preserving position in slips.

The prediction concerning the two sonority-rising onset clusters /tl/ and /dr/ was the same in both experiments: the unattested cluster /tl/ should show a higher illegal movement rate than /dr/. This was not confirmed in either experiment, however, since both clusters preserved position in erroneous syllables 100% of the time, meaning that the universal sonority-based markedness constraint governing /dr/ is not stronger than the language-wide constraint governing /tl/.

Although the prediction concerning /sk/ and /tl/ constraint adherence rates—that /sk/ would disobey constraints at a higher rate than /tl/—was the same in both Experiment 1 and Experiment 2, the reasoning was different, as the strength of the constraints governing /sk/ was

not the same in the two experiments. The constraints acting on /tʌ/ were greater than those acting on /sk/ in both experiments, however, making for identical predictions, which the results upheld. In Experiment 1, /sk/ showed a higher illegal movement error rate (at 39.3%) whose slips preserved position 100% of the time. In Experiment 2 as well, /tʌ/ exhibited no illegal movement errors, while the majority of /sk/ slips—93.2%—were illegal.

In both experiments, it was predicted that /sk/ would disobey constraints at a higher rate than /dr/, but in Experiment 1 the reasoning involved a comparison of language-wide constraints (/dr/) and experiment-wide constraints (/sk/), while in Experiment 2 the comparison involved language-wide constraints (/dr/) and local positional constraints (/sk/). The prediction was upheld in both experiments.: /dr/ was involved in zero illegal movement errors in both experiments, but /sk/ underwent illegal movement at a rate of 39.3% in Experiment 1 and 93.2% in Experiment 2.

The prediction concerning illegal movement error rates of the two unattested onset clusters /gv/ and /tʌ/ and the reasoning behind the prediction was the same in both experiments: if markedness does constrain phonotactic learning, the constraint adherence rate for an unfamiliar cluster would be influenced by the universal SSP constraint restricting clusters with sonority-rising profiles to onset position. That is, /gv/ would show a higher illegal movement error rate—or, a lower rate of constraint adherence—than would /tʌ/. This prediction was confirmed: in both experiments, the rate of errors in which /gv/ erroneously moved to the coda position was 40% while /tʌ/ never moved to the coda position.

Additionally, the results concerning the clusters /gv/ and /tʌ/ accord with the expectation that if participants' sensitivity to sonority markedness generalizes to unattested clusters, then the marked cluster /gv/ should undergo cluster repair at a higher rate than the unmarked cluster /tʌ/ .

This was confirmed, as the results showed that the /gv/ was repaired more than twice as much as /tl/ in both experiments: /gv/ and /tl/ repair accounted for 38.0% and 16.4%, respectively, of all cluster repair errors in Experiment 1 and 42.8% and 20.5% of all repair errors, respectively, in Experiment 2.

Of all legal movement errors involving clusters that were always constrained to the onset in both experiments, the unfamiliar clusters /gv/ and /tl/ together accounted for only 23.0% and 36.4% in Experiment 1 and 2, respectively. A possible explanation may lie in the fact that, due to training with the unfamiliar onset clusters, participants were especially focused on those clusters, directing that awareness to preserving syllable position during movement errors. In the present study, syllables with correctly produced /tl/ and /gv/ onsets were more likely to have errors in the coda than syllables with any other correctly produced onset (9.4% versus 6.5% of syllables, respectively).

Instance theories hold that each experience of an instance produces a separate memory trace, with the most recently encountered instances the most accessible. The granularity of the basic unit, or instance, that acts as input to this type of phonotactic learning model dictates the nature of production errors. Syllable instance theory predicts that syllables that are erroneous productions are more likely to take the form of syllables that the subject has recently produced, as these would theoretically be more accessible than syllables that the speaker has not recently encountered in the stimuli (Dell et al. 2000). In other words, erroneous syllables are more likely to be those that appear in the stimuli. Dell et al. (2000) found no evidence to support this, however, concluding that the experiment-wide effect is most likely not due to the syllable-instance theory or any theory that links the effect with a lexicon of stored syllable types. In the

present study as well, many erroneous syllables were not ones recently produced, contrary to the prediction of syllable instance theory.⁷

6.2 Potential weak points and future extensions

There were a number of potential weak points in the experiment design, such as coding of the data and reliability of transcription. The recordings were transcribed by two individuals: the author and a second coder who received specific instructions in how to transcribe the recordings but was otherwise uninformed of the study objectives. The agreement rate in transcription (evaluated from an overlapped 11% of the data from Experiment 1 and Experiment 2) was 90.3%, leaving room for higher coder reliability to bolster the validity of the results.

Another potential weak area pertains to the choice of clusters presented in the stimuli. The set of onset clusters and the set of coda clusters were not perfectly balanced in terms of features of markedness and familiarity, potentially distorting the results—as the motivation for the symmetry was to equate for error opportunities among the clusters and individual consonants.

Aspects of the experiment design that may constitute weak points, can, when addressed, present potential expansions to the study. For example, the current experiment design means that any prediction for an onset cluster is not necessarily valid for that cluster’s coda analogue.

7. Determining whether erroneous syllables were restricted to recently produced syllables in the present study is not quite straightforward. Out of the 3979 erroneous syllables produced in both experiments, 160 (4.0%) appeared in the stimuli and 3819 (96.0%) did not. These results may be misleading, however, due to the high number of cluster-repaired syllables—for example, should an erroneous production like *gəvevd* (with target syllable *gvevd*) count as an occurring syllable? Ultimately, this may be a moot point: even when *gəvevd* is considered equivalent to *gvevd*, the majority of erroneously produced syllables are not ones that appeared in the stimuli. Out of the 3979 erroneous syllables produced in both experiments, 1511 (38.0%) appeared in the stimuli and 2468 (62.0%) did not.

Parallel predictions would assume that, for example, /vd/ is dispreferred in codas over /lg/ in the same manner that /gv/ is dispreferred in onsets relative to /tl/—but that is not the case, and such a prediction would be inaccurate. Accordingly, the predictions, results, and other discussion concerning error types and rates applied to onset clusters exclusively. A related potential extension entails modifying and expanding the experiment design so as to be able to speculate productively about the behavior of coda clusters so that the results involving the coda clusters are meaningful in and of themselves as well as in comparison with the data involving the onset clusters.

Other ways to expand on the experiment design and findings in the present study include testing subjects over multiple sessions spanning several days (as in Dell et al. 2000), which would allow for an investigation into the effects of increasing amounts of exposure to the patterns in the stimuli. This would also have the added benefit of increasing the volume of data to maximize opportunities for illegal movement errors involving /tl/ and /dr/—in the present study, predictions involving these clusters were not confirmed as neither cluster underwent illegal movement. The same purpose would be served by testing more subjects.

Another potential extension pertains to degrees of markedness in the stimuli. The current study classified onset clusters as either unmarked or marked; however, it is possible to expand this binary distinction into additional degrees of markedness, as in, for example, Berent et al. (2007), who investigated onset clusters with sonority-falling, as well as sonority-rising and sonority-plateauing, profiles.

6.3 Concluding remarks

The results show that speakers were able to learn a variety of positional patterns involving both familiar and unfamiliar sounds following only brief production experience; moreover, the differences in rates of adherence to the various constraints revealed a markedness effect on learning, limiting the extent to which speakers were able to abstract patterns from recently available input. The results thus support the notion that phonological constraints as embodied by the speech patterns of an individual are continually dynamic, emerging and changing with exposure to language throughout one's lifetime—but moderated by constraints that reflect preferences for universally unmarked structures.

The idea that speakers are able to make apparently universally applicable generalizations from recent productions has implications for models of phonotactic learning, as it precludes theories that describe constraint acquisition in terms of systems of immutable rules and/or parameters.

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